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Editor's Page

Ending plastic waste

Last month, almost 30 global companies announced the formation of an alliance to address the impact that plastic waste is having on our environment, with particular focus on our oceans. The Alliance to End Plastic Waste (AEPW; www.endplasticwaste.org) has committed over $1 billion, and aims to invest $1.5 billion over the next five years toward the ambitious goal of eliminating plastic waste.

The founding members of the AEPW, which include representatives from industries across the value chain of plastics manufacture and use, are: BASF, Berry Global, Braskem, Chevron Phillips Chemical Company, Clariant, Covestro, Dow, DSM, ExxonMobil, Formosa Plastics Corp. USA, Henkel, LyondellBasell, Mitsubishi Chemical Holdings, Mitsui Chemicals, NOVA Chemicals, OxyChem, PolyOne, Procter & Gamble, Reliance Industries, the Saudi Basic Industries Corp. (SABIC), Sasol, SUEZ, Shell, SCG Chemicals, Sumitomo Chemical, Total, Veolia and Versalis (Eni).

Industry steps up to the challenge

While plastics afford many advantages that have contributed to their ever-increasing use, most plastic waste is not being recycled and plastic debris is a global environmental concern (for more, see Embracing a circular economy; *CE* June 2018, p. 5). Waste plastic, however, has value with the potential to be tapped, and companies are working to do this.

BASF, for example, has undertaken a project called ChemCycling, where using thermochemical processes, plastic waste that is not currently being recycled, can be broken down to oil or gaseous products that can then be used as raw materials. In December, the company announced that it has, for the first time, manufactured products based on chemically recycled plastic waste.

Also in December, SABIC signed a memorandum of understanding with Plastic Energy, Ltd. The two companies plan to build the first commercial plant in Europe to refine and upgrade a feedstock that will be made from recycled, low-quality, mixed-plastic waste. The target date for commercial production is 2021.

In October, Veolia and Unilever announced a collaboration agreement to work on emerging technologies to help reduce plastic waste. Unilever committed to use at least 25% of recycled plastic in its packaging by 2025.

These efforts, and more by both industry and academia, are all working toward creating a plastics circular economy. The AEPW looks to enhance individual efforts through cooperation in the alliance.

The Alliance to End Plastic Waste

The Alliance is a non-profit organization and has identfied four key areas for its work: Infrastructure development; Innovation; Education and engagement; and Clean-up.

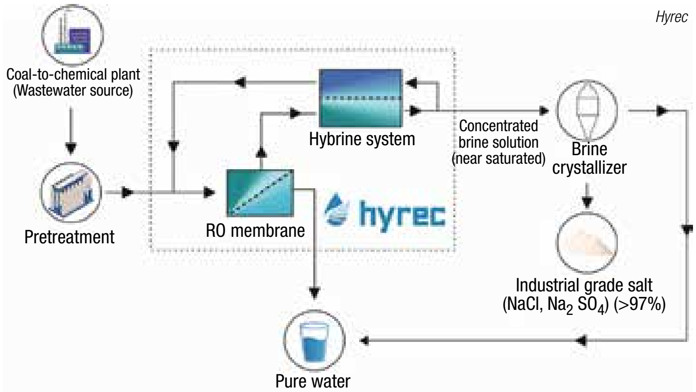
The founding companies of the AEPW have strong resources and capabilities that are much-needed to address the plastics-waste problem. The announcement of the alliance brings a welcome focus of these resources in a cooperative effort for real change to this global challenge.

For more on the advances being made in recyclng plastic waste, look for our Newsfront on this topic in next month's issue of *Chemical Engineering*. ■

Dorothy Lozowski, Editorial Director

Industrial-grade salt recovery from zero-liquid-discharge process

Edited by:
Gerald Ondrey



A process that increases the water-recovery from reverse osmosis (RO) while producing a salt byproduct is being developed by Hyrec (Urla/Izmir, Turkey; www.hyrec.co). The process, which uses osmotically assisted RO (OARO), could be especially beneficial in coal-to-chemicals (CTC) plants in China, which require large volumes of water, but are in water-stressed regions, says business development specialist Günseli Mendi. The process can also be used for concentrating waste brines generated in other industries, such as textiles, mining, and oil and gas, she says.

In OARO (diagram), permeate flows from the high-pressure side to the low-pressure side of the membrane, as in standard RO. However, unlike RO, OARO employs two feed streams. The first feed stream is the same RO feed stream, which is dewatered through the membranes, and leaves the module with increased concentration. Some part of this concentrated stream is then recycled back to the opposite side of the membranes as a second feed stream, diluted through the membranes and leaves the module with decreased concentration. The reduced osmotic-pressure difference between the feed and the permeate sides allows the treatment of ultra-saline feeds at pressures as low as 70 bars. Thus, OARO's maximum recovery is not limited by the burst pressure of standard RO membranes, says Mendi.

Hyrec's OARO process extends the range of RO to very high salinities, salinity ranges that have been dominated by thermal systems. Hyrec can concentrate brine up to saturation levels from a saline influent of about 40,000 parts per million (ppm) total dissolved solids (TDS), at a hydrostatic pressure of 70 bars. In such cases, it consumes approximately 6 kWh/m^3 of recovered water. The OARO method significantly decreases operational and capital costs, compared to conventional electrodialysis, forward osmosis and mechanical vapor compression for brine concentration, says the company.

Since February 2018, Hyrec has been operating a near commercial-sized plant with a feed capacity of 7.35-m^3/h. Industrial scale projects are expected to take place in conjunction with commercial partners from the U.S., Indonesia, Kuwait, Japan, India and Germany in mid-2019. "We plan to be in a fully commercial stage by the end of 2019," says Mendi.

NEW PDH CAPABILITY

A new catalyst for propane dehydrogenation (PDH) that does not include precious metals has been developed by KBR Inc. (Houston, Tex.; www.kbr.com). The new catalyst is incorporated into KBR's new PDH technology, known as K-PRO, which was announced in late December. K-PRO is based on the company's catalytic olefins technology, which is designed to convert low-value olefinic, paraffinic and mixed streams into propylene and ethylene.

According to KBR, K-PRO offers high propylene selectivity and conversion in PDH applications. K-PRO is also said to deliver significant capital cost (20–30% in internal studies) and operating cost advantages when compared with conventional designs. The savings arise from a fluidized-bed design, which is more efficient than existing fixed or moving-bed reactors. Plants based on the new K-PRO technology will be designed as standalone propylene production units independent of a steam cracker or a fluid-catalytic cracking (FCC) unit. Additionally, existing PDH operating

(Continues on p. 8)

A low-pressure process to leach metals from laterite ores

Queensland Pacific Metals (Brisbane, Australia), a subsidiary of Pure Minerals (Perth, Australia; www.pureminerals.com.au) will use Direct Nickel Projects' (Perth, Australia) proprietary technology to process New Caledonian nickel and cobalt ore, following favorable test results.

Core Metallurgy (Brisbane, Australia) has assessed the leach characteristics of the core samples. Test work using the Direct Nickel process yielded 98% nickel, 98.1% cobalt, 95.4% aluminum, 96.1% iron, 95.3% magnesium, and 97.3% scandium. This was extracted from the samples that graded 1.70% nickel, 0.15% cobalt, 1.37% aluminum, 35.55% iron, 6.14% magnesium, and 40 parts per million scandium.

Direct Nickel chief technologist Fiona McCarthy says the kinetic leach tests completed by Core Metallurgy are very encouraging. "Extraction levels are at the top level of leach tests we have completed on laterite ores around the world and the leach times also appear particularly short," she says. Now, Queensland Pacific will conduct an extensive laboratory program of tests on the Direct Nickel process, and a continuous pilot plant trial will be carried out at the CSIRO Minerals' facility in Western Australia.

Direct Nickel's technology uses nitric acid to leach minerals in laterite ores at atmospheric pressure. Currently, nickel and cobalt laterite processing involves high-pressure acid leaching, which requires a large capital outlay and is costly to operate. It also generates a large amount of waste.

Queensland Pacific has contracts to import and treat 600,000 metric tons per year of New Caledonian nickel and cobalt laterite ore. The company plans to process the ore at a plant in Townsville, in North Queensland.

New Caledonia hosts the world's largest laterite ore reserves.

units can be easily modified to benefit from the superior process performance and lower operating cost, KBR says.

LITHIUM CARBONATE

Standard Lithium Ltd. (Vancouver, B.C., Canada; www.standardlithium.com) has produced its first quantity of battery-quality (>99.56% purity) lithium carbonate at the company's prototype Lithium Carbonate Crystallization Pilot Plant operated by Saltworks Technologies Inc., at their facility in Richmond, British Columbia, Canada. The Crystallization Pilot Plant is based on Standard Lithium's proprietary technology.

The prototype crystallization plant was operated as a two-stage crystallization process. The initial solids produced from the first run, were re-solubilized and crystallized a second time. The solids produced from this second run (second stage as reported here) were then hot-washed, filtered and dried. The resulting lithium carbonate crystals were a fine free-flowing powder and were >99.56% pure. Despite the fact that the synthetic starting solution had more impurities than are anticipated to be present in the solution the upstream process will produce, lithium carbonate purity targets were met, giving a measure of comfort that the crystallization process is

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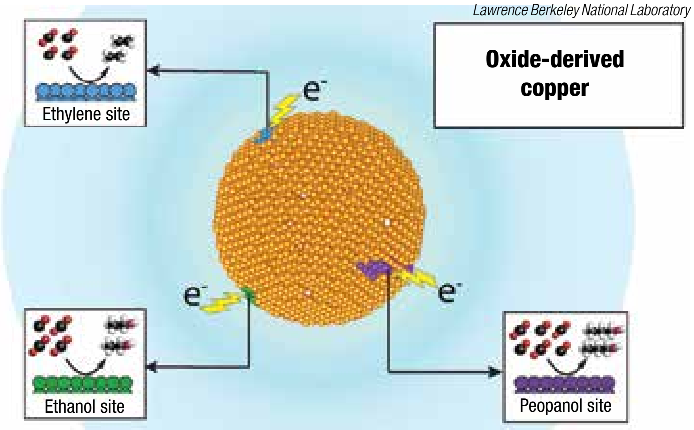
CO_2-to-chemicals effort boosted by electrocatalysis studies



The quest to generate chemicals and fuels from exhaust or atmospheric carbon dioxide got a boost from a series of recent studies by researchers at Lawrence Berkeley National Laboratory (LBL; Berkeley, Calif.; www.lbl.gov), in which the scientists proved the viability of an electrocatalytic process for making ethanol, propanol and ethylene from CO_2 using renewably generated electricity. In addition, the LBL team has shown a pathway toward highly selective copper electrocatalysts that could be engineered to produce a single product, thereby eliminating the need for downstream separation.

In one project, the LBL scientists, led by Joel Ager, a researcher at the Joint Center for Artificial Photosynthesis, were able to exceed the efficiency of natural photosynthesis in converting CO_2 into two-carbon compounds and oxygenates using an "all-purpose" silver-copper catalyst and electrons from solar photovoltaic cells.

In another project, the team showed that engineered copper catalysts could potentially be highly selective for specific chemicals. "We used cycles of oxidation and reduction to create copper active sites, similar to the methods used to engineer heterogeneous catalysts for industrial applications," says Ager. The oxidation and reduction process created nanostructured morphology in the catalyst material that promotes CO_2 reduction chemistry.

Ager and colleagues then used carbon monoxide labeled with carbon-13 radioisotopes to discern three distinct types of active sites in the copper catalyst material. Each type of active site results in different end products (ethanol, propanol or ethylene). "CO is a reaction intermediate that combines with other CO molecules to form C–C bonds," Ager explains, "and those C–C bonds reflect the relative abundance of carbon-13 and carbon-12 at the site that formed them." The study confirmed that the three product groups came from different active sites, opening the possibility that catalysts could be engineered to exhibit only a single type of active site. This would theoretically produce a single product selectively and eliminate the need to separate a mixed product stream by distillation or other means, Ager says.

The LBL team is looking at how the orientation and spacing of the atoms in the different types of active sites gives rise to specific products.

A photocatalyst for reducing CO_2 without precious metals

The research group of professor Osamu Ishitani at the Tokyo Institute of Technology (Japan; www.titech.ac.jp), in collaboration with the Institute of Advanced Industrial Science and Technology (AIST), has successfully demonstrated highly efficient, selective and durable photocatalytic CO_2-reduction systems that only use abundant elements for the first time. The CO_2-reduction photocatalysts use $[Cu_2(P_2bph)_2]^{2+}$ (CuPS) as a redox photosensitizer, where P_2bph = 4,7-diphenyl-2,9-di(diphenylphosphinotetramethylene)-1,10-phenanthroline; and fac-Mn(X_2bpy)$(CO)_3$Br (Mn(4X)) as the catalyst, where X_2bpy = 4,4'-X_2-2,2'-bipyridine (X = –H and –OMe) or Mn(6mes), where 6mes = 6,6'-(mesityl)2-2,2'-bipyridne). The most efficient photocatalysis was achieved with Mn(4OMe), which had a total quantum yield for CO_2 reduction products of 57%, a turnover number (based on the Mn catalyst) of over 1,300, and a selectivity for CO_2 reduction of 95%. Electronic and steric effects of the substituents (X) in the Mn complexes largely affected both the photocatalytic efficiency and the product selectivity, according to the researchers.

For example, the highest selectivity of CO formation was achieved by using Mn(6mes) (selectivity S_{CO} = 96.6%), whereas the photocatalytic system using Mn(4H) yielded HCOOH as the main product (S_{HCOOH} = 74.6%) with CO and H_2 as minor products (S_{CO} = 23.7%, S_{H2} = 1.7%). In these photocatalytic reactions, CuPS played a role as an efficient and very durable redox photosensitizer, while remaining stable in the reaction solution even after a turnover number of 200 had been reached (the catalyst used had a turnover number of over 1,000).

The researchers are planning to enhance the performance of the newly developed photocatalyst and also to combine their achievement with a semiconductor photocatalyst that uses water as the reducing agent.

New catalysts enable CO_2-neutral olefins production via methane reforming

Today, olefins are mainly made either by naphtha cracking or by the catalytic conversion of dimethyl ether (DME), which is in-situ made from synthesis-gas- (syngas) derived methanol (methanol-to-olefin processes). Both naphtha cracking and syngas production (from steam-methane reforming; SMR) require fossil fuels to drive the endothermic reactions, resulting in considerable emissions of CO_2.

In an effort to reduce CO_2 emissions from olefins production, BASF SE (Ludwigshafen, Germany; www.basf.com), together with industrial and academic partners, is developing an alternative route to DME that reduces the CO_2 footprint by 50–70%, according to Nils Bottke, head of petrochemical catalyst research at BASF, who presented an update of this five-year research project during a BASF Research Press Conference last month in Ludwigshafen.

The new route to DME is a two-step process. In the first step, syngas is made by "dry reforming" of methane — that means CO_2 is used as a reagent instead of water, as in conventional SMR. As a result, this step is CO_2 neutral to slightly negative, explains Bottke. In contrast, SMR releases about 350 kg of CO_2 per 1,000 Nm^3 of syngas. To perform dry reforming, BASF developed two spinel-type catalysts based on nickel and cobalt. In addition to reducing the steam demand by up to 60%, dry reforming produces a CO-rich syngas ($CO:H_2$ = 1:1) that is optimal for directly making DME in the second step.

A new catalyst system — a combination of two catalysts that perform bifunctional catalysis — was also developed for the second step, which enables the direct conversion of CO-rich syngas into DME (eliminating the methanol intermediate step). The zeolite-based catalyst system also has a "self-cleaning" feature that prevents deactivation, says Bottke.

Together with industrial partner Linde AG (Munich, Germany; www.linde.com), BASF plans to commercially launch the dry-reforming catalysts in 2020, and the syngas-to-DME catalyst system in 2022.

robust. Additional optimization is now being performed, and the technical team will also be adjusting the composition of the input feed stream so as to optimize how the two parts of Standard Lithium's proprietary technologies work together.

MXENES REACTIVITY

Researchers at Missouri University of Science and Technology (Rolla, Mo.; www.mst.edu) have discovered that two-dimensional (2-D) titanium carbide materials, or MXenes, can react with water with no other oxidizers involved. Their finding may lead to new insights into the unusual chemistry of MXenes and the impacts on MXenes' storage and device-manufacturing.

MXenes are one of the largest families of 2-D materials. They are a few-atom-thick sheets with the structures of transition-metal carbides

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and nitrides. Their distinctive properties, such as high electrical conductivity combined with their ability to disperse in water, make them potential candidates for applications in energy storage and harvesting (batteries, supercapacitors and triboelectric nanogenerators, which convert wasted frictional energy into electricity), according to Vadym Mochalin, associate professor of chemistry.

"The reactivity of MXenes toward water we've demonstrated not only changes the common perception about resistance of titanium carbide to hydrolysis in ambient conditions, but also points out the striking differences in chemical properties between bulk and 2-D forms of the same material," says Mochalin.

Mochalin and lead author Shuohan Huang, a doctoral student working in Mochalin's research group, discuss their findings in a paper published last month in *Inorganic Chemistry*. "Our new findings are important because now we know it is water itself, rather than oxygen, that MXenes need to be protected from during manufacturing and storage," says Huang.

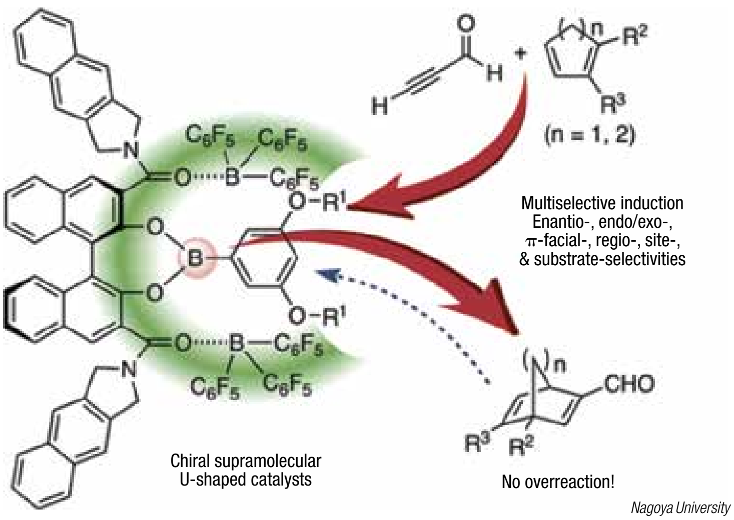
WATER SPLITTING

A team of researchers from East China University of Science and Technology (Shanghai, China; www.ecust.edu.cn) and the University of Liverpool (U.K.; www.liverpool.ac.uk) led by University of Liverpool professor Andrew Cooper, has produced a crystalline covalent organic framework (COF) that exhibits a much higher activity for photochemical hydrogen evolution (water splitting) than its amorphous or semicrystalline counterparts. According to the researchers, the COF, based on a benzobis(benzothiophene sulfone) moiety, is stable under long-term visible irradiation and shows steady photochemical hydrogen evolution with a sacrificial electron donor for at least 50 hours.

The researchers attribute the high quantum efficiency of fused-sulfone-COF to its

(Continues on p. 11)

Artificial enzyme shows multiple selectivity



Nagoya University

Professor Kazuaki Ishigreo and colleagues at Nagoya University (Nagoya, Japan; http://en.nagoya-u.ac.jp) have shown that a chiral, supramolecular, U-shaped, boron Lewis acid catalyst (diagram) promotes the unprecedented multiselective Diels–Alder reaction of propargyl aldehyde with cyclic dienes. The Diels–Alder reaction, which is a traditional [4 + 2] cycloaddition with two carbon–carbon bond formations, is one of the most powerful tools for synthesizing versatile and unique six-membered ring compounds.

Independent from the substrate, enantio-, endo/exo-, π-facial-, regio-, site-, and substrate-selectivity could all be controlled by this U-shaped catalyst.

The obtained reaction products could enable the concise synthesis of chiral diene ligands and a key intermediate of (+)-sarkomycin, an anti-tumor agent. The results are expected to contribute to the development of artificial enzyme-like supramolecular catalysts for multi-selective reactions, which will be able to target organic compounds that have thus far eluded synthesis.

Co-electrolysis makes 'green' syngas in a single step

Last month, Sunfire GmbH (Dresden, Germany; www.sunfire.de) reported the successful startup and test run (more than 500 h) of a high-temperature, co-electrolysis system at its Dresden site since November 2018. The technology, called Sunfire-Synlink, is based on solid-oxide cells and enables highly efficient production (in the future, approximately 80% efficiency on an industrial scale) of synthesis gas (syngas) in a single step from water (steam), CO_2 and renewable electricity (solar, wind, hydroelectric). This significantly reduces investment and operating costs for power-to-x (PTX) projects working to produce carbon-neutral liquid fuels (for more on PTX, see *Chem. Eng.,* January 2019, pp. 14–17).

Sunfire achieved the technological breakthrough within the framework of the Kopernikus project Power-to-X, funded by the German Federal Ministry of Education and Research, in conjunction with the Karlsruhe Institute of Technology (KIT; Germany; www.kit.edu). The 10-kW co-electrolysis plant, which produces up to 4 Nm^3/h of syngas, will be delivered to Karlsruhe in the next few weeks, where it will be combined with technologies from Climeworks AG (Direct Air Capture), Ineratec GmbH (Fischer-Tropsch synthesis) and KIT (hydrocracking) in a container to produce a self-sufficient facility. The aim is to demonstrate the integrated production of e-crude, a synthetic crude-oil substitute, by the end of August.

Furthermore, on January 1, 2019, Sunfire began the process of scaling-up the high-temperature co-electrolysis process to an industrial scale — initially with an input power of 150 kW (d.c.) — as part of the SynLink project funded by the Federal Ministry of Economics and Energy. This multipliable co-electrolysis module is to be used by Nordic Blue Crude, the Norwegian project partner. The first commercial plant is to be built there, and will produce 10 million L/yr (8,000 m.t/yr) of e-crude.

Also last month, Sunfire acquired a new lead investor and technology partner, Paul Wurth S.A. (Luxembourg; www.paulwurth.com) a leading mechanical and plant-engineering company for the metals industry. The investment round, which involved former investors, yielded an additional €25 million in venture capital. Sunfire will use the funds to implement commercial multi-megawatt electrolysis and PTX projects.

Plasma-based electrolysis makes ammonia at ambient conditions

Researchers from Case Western Reserve University (CWR; Cleveland, Ohio; www.case.edu) have shown that a hybrid electrolytic system using a gaseous plasma electrode can produce ammonia from water and nitrogen at ambient temperature and pressure — without any catalytic material surface.

Distinct from other plasma-based processes, such as natural lightning or the Birkeland-Eyde process (a pre-Haber-Bosch method that uses an electric arc in air to make nitrates), the CWR method takes place in a N_2 atmosphere in the absence of air. The process is similar to other electrochemical approaches, except that the metal cathode is replaced by a plasma formed in the gap between a nozzle and the surface of a dilute sulfuric acid solution, which supplies protons for the process. At the cathode, N_2 and energetic electrons from the plasma are injected into the solution, and solvated electrons [e^-(aq)] — a powerful reducing agent — are formed. Although the exact mechanism is not yet well understood, the researchers believe the solvated electrons cause a cascading reaction at the interface, whereby protons (H^+) are reduced to hydrogen radicals (H·), and N_2 is reduced to form NH_3 (aq).

In the laboratory, a Faradaic efficiency of up to 100% has been observed, and NH_3 is produced with almost 100% selectivity at a production rate of 0.44 mg/h. These results and more details were reported last month in *Science Advances*, with lead authors Julie Renner, associate professor, and Mohan Sankaran, Goodrich Professor of Engineering Innovation, at the Case School of Engineering.

Although the research is still in its infancy, the researchers believe that the plasma electrolytic system may offer a scalable, highly selective alternative to the conventional Haber-Bosch (H-B) route to NH_3. Further work is needed to reduce the power consumption — which is "considerably higher" than Haber-Bosch or existing electrosynthesis methods. But the plasma-based route could be economical for small-scale distributed networks, especially when coupled with renewable electricity sources, the researchers report. ■

crystallinity, its strong visible light absorption, and its hydrophilic 3.2-nm mesopores. These pores allow the framework to be dye-sensitized, leading to a further 61% enhancement in the hydrogen evolution rate up to 16.3 mmol/g/h.

"To achieve high hydrogen evolution rates, you need good water affinity, broad light adsorption, high surface area, and high crystallinity. By introducing all of these features in one material, we got a very active photocatalyst," says Xiaoyan Wang, a University of Liverpool Ph.D. candidate who led the experimental work.

The project was funded by the Engineering and Physical Science Research Council (Swindon, U.K.), the Leverhulme Trust (London, U.K.) and the European Research Council (Brussels, Belgium). ❑

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Plant Watch

Lotte BP Chemical to expand petrochemicals production in Ulsan

January 14, 2019 — BP plc (London; www.bp.com) and Lotte Chemical Corp. (Seoul, South Korea; www.lottechem.com) have agreed to significantly expand production capacity at their joint venture (JV), Lotte BP Chemical Co., in Ulsan, South Korea. The expansion is expected to add 100,000 metric tons per year (m.t./yr) of acetic acid capacity by May 2019 and to double the current 200,000-m.t./yr vinyl acetate monomer (VAM) capacity with the addition of a second VAM plant by the end of 2020. The new expansion will bring total production capacity at the site to over 1 million m.t./yr.

Aemetis completes expansion of biodiesel plant in India

January 11, 2019 — Aemetis, Inc. (Cupertino, Calif.; www.aemetis.com) has completed a two-year upgrade of its Kakinada, India biodiesel and glycerin plant. The upgrades included: installation of a pretreatment unit to process l ower-cost and waste feedstock into oil; expansion of boiler and other utility capacities; and implementation of environmental systems to enable full production of 50 million gal/yr of biodiesel and bio-oil.

Shell starts production at new petrochemicals unit in Louisiana

January 7, 2019 — Shell Chemical LP (Houston, Tex.; www.shell.us) started production of the fourth alpha-olefins (AO) unit at its Geismar, La. chemical manufacturing site. The capacity expansion added 425,000 m.t./yr of AO production, bringing total AO production at Geismar to more than 1.3 million m.t./yr.

Air Products to build second liquid-H_2 production facility in California

January 7, 2019 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) plans to build a second liquid-H_2 production facility in California to meet increasing product demand from several customer markets. Project development work is already underway, with an anticipated facility startup during the first quarter of 2021.

Indorama starts up purified isophthalic acid plant in Alabama

January 4, 2019 — Indorama Ventures Public Co. Ltd. (IVL; Bangkok, Thailand; www.indoramaventures.com) commenced commercial production of purified isophthalic acid (PIA) at its Decatur, Ala. site. The Decatur PIA plants complement IVL's existing PIA plant at IVL Quimica, Spain. The two PIA plants have a combined nameplate capacity of 440,000 m.t./yr.

Sipchem starts commercial operation of EVA film plant

January 3, 2019 — Saudi International Petrochemical Co. (Sipchem; Al Khobar, Saudi Arabia; www.sipchem.com) began commercial operations of a new ethylene vinyl acetate (EVA) film plant in Hail Industrial City. The new plant's production capacity is 4,000 m.t./yr of EVA film. The cost of the project is SR 150 million (around $40 million).

BASF to expand capacity for methane sulfonic acid at its Ludwigshafen site

December 20, 2018 — BASF SE (Ludwigshafen, Germany; www.basf.com) intends to expand the production capacity for methane sulfonic acid (MSA) at its Ludwigshafen site by around 65% and increase global MSA capacity to 50,000 m.t./yr. The additional capacity is expected to be available late in 2021. MSA is a biodegradable alternative to other acids, such as sulfuric, phosphoric or acetic acid.

Ineos Styrolution progresses plans for new ASA plant in Texas

December 20, 2018 — Ineos Styrolution (Frankfurt, Germany; www.ineos-styrolution.com) has announced the final investment decision to construct a new acrylonitrile styrene acrylate (ASA) plant at its site in Bayport, Tex. The new plant's expected capacity is 100,000 m.t./yr and startup is scheduled for 2021.

BASF invests in new mobile-emissions catalysts production facility in Shanghai

December 20, 2018 — BASF is investing in a new production facility for mobile-emissions catalysts at its Pudong site in Shanghai, China. The new 30,000-m^2 facility will house multiple manufacturing lines. Construction is underway, with startup planned for the end of 2019.

Air Products to build three nitrogen plants in the Netherlands

December 19, 2018 — Air Products will supply three nitrogen-generation plants for N.V. Nederlandse Gasunie, to be located in Zuidbroek, near Groningen, the Netherlands. The three plants will produce a combined 180,000 m^3/h of nitrogen when brought onstream in October 2021.

Mergers & Acquisitions

Alpek to acquire PET recycling plant in Indiana

January 10, 2019 — A subsidiary of Alpek S.A.B. de C.V. (San Pedro Garza Garcia, Mexico; www.alpek.com) signed an agreement with Perpetual Recycling Solutions LLC to acquire a polyethylene terephthalate (PET) recycling plant in Richmond, Indiana. The acquired plant produces approximately

45,000 m.t./yr of recycled PET (rPET) flake. This acquisition will complement Alpek's existing PET recycling operations in Argentina and North Carolina.

Saint-Gobain to divest silicon carbide division

January 10, 2019 — Saint-Gobain S.A. (Paris, France; www.saint-gobain.com) received a purchase offer from OpenGate Capital to acquire Saint-Gobain's silicon carbide division. Saint-Gobain produces silicon carbide grains and powder, with annual sales of around €120 million. The transaction should be effective in the first half of 2019.

PolyOne acquires fiber and composites manufacturer

January 3, 2019 — PolyOne Corp. (Cleveland, Ohio; www.polyone.com) acquired Fiber-Line (Hatfield, Pa.; www.fiber-line.com), a specialist in customized engineered fibers and composite materials, for $120 million. Fiber-Line has five manufacturing sites in North America, Europe and Asia. PolyOne expects the acquisition to add nearly $100 million in revenue during 2019.

Indorama acquires PET recycling facilities in Alabama

January 2, 2019 — Indorama has entered into an agreement to acquire a PET recycling facility from Custom Polymers PET in Alabama. The facility consists of two production lines — rPET flake and food-grade rPET pellets — with a combined capacity of 31,000 m.t./yr.

Saudi Aramco takes full ownership of Arlanxeo joint venture

January 2, 2019 — Saudi Aramco (Dhahran, Saudi Arabia; www.saudiaramco.com) completed the acquisition of Lanxess AG's (Cologne, Germany; www.lanxess.com) interest in Arlanxeo Holding B.V., a Netherlands-based JV launched in 2016 focused on synthetic rubber and elastomers. Saudi Aramco's purchase of Lanxess' 50% share in Arlanxeo, valued at €1.5 billion, makes it the sole owner of Arlanxeo.

Indorama acquires German PET business from Invista

December 20, 2018 — Indorama has entered into an agreement with Invista (Wichita, Kan.; www.invista.com) to acquire Invista Resins & Fibers GmbH, which owns a high-value-added PET manufacturing facility located in Gersthofen, Germany. The Gersthofen site has a combined capacity of 282,000 m.t./yr. The transaction is expected to be completed in the first quarter 2019.

Clariant and Saudi Kayan to evaluate alkoxylates joint venture

December 20, 2018 — Clariant (Muttenz, Switzerland; www.clariant.com) signed an agreement with Saudi Kayan to evaluate the formation of a JV with the aim of establishing a manufacturing facility for alkoxylates. This facility is planned to combine Clariant's alkoxylates production process with Saudi Kayan's raw materials, and would be based within Saudi Kayan's petrochemical complex in Jubail Industrial City, Saudi Arabia. ■

Mary Page Bailey

Artificial Intelligence: A New Reality for Chemical Engineers

From process and materials development to maintenance and logistics, artificial intelligence (AI) is emerging as a transformative force across the chemical process industries

IN BRIEF

GLOBAL DATA INTEGRATION

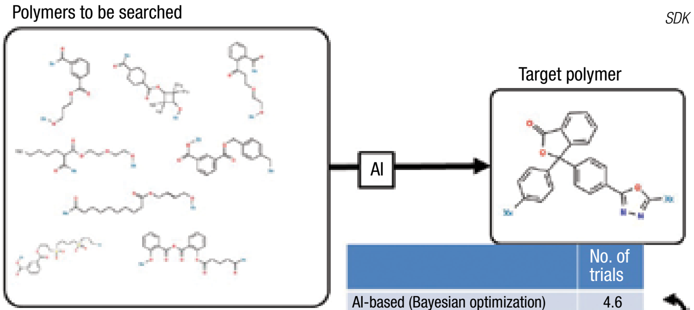
ACCELERATING PRODUCT DEVELOPMENT

ENHANCING OPERATIONS AND UPTIME

SAFETY AND ENVIRONMENTAL UPGRADES

As in many other sectors, artificial intelligence (AI) technologies are beginning to emerge in the chemical process industries (CPI). While AI-assisted solutions, and other associated technologies, such as robotic process automation (RPA), Internet of Things (IoT), automated drones and quantum computing, are still relatively new for many CPI applications, developers and users alike are realizing their potential benefits for expediting research and development (R&D), predictive maintenance, process optimization and more.

SDK



	No. of trials
AI-based (Bayesian optimization)	4.6
AI-based (without consideration of estimated prediction error)	24
Random selection	192

About 1/40th

FIGURE 1. Using AI-assisted polymer design, the number of trials required to target a particular material property is drastically reduced

Global data integration

Within its Smart Operations initiative, Henkel AG & Co. KGaA (Düsseldorf, Germany; www.henkel.com) is utilizing AI capabilities in its global process operations and supply chain. "We use AI to run efficient analyses of complex data arrays for achieving higher production performance, quick product innovation and scaleup for our self-adjusting production systems," explains Sandeep Sreekumar, global head of Adhesive Digital Operations at Henkel. "Our focus is not only on collecting internal manufacturing data, but also on actively working with customers on data collection opportunities during product usage to make improvements and adjust to changing customer needs," says Sreekumar. Henkel currently applies externally built AI technologies, but the company envisions creating an ecosystem where both internal and third-party solutions co-exist and establishing a fully transparent global supply-chain and operations network that is both automated and self-adjusting to variability, explains Tim Gudszend, global head of Adhesive Technologies and Investment at Henkel. The company's "smart factory" technologies are designed to enhance understanding of raw materials availability and current production status to better advise operations personnel on how to adjust the production process to improve performance. "By analyzing these data, we have implemented significant raw-material yield improvements and increased performance quality within these plants," adds Gudszend.

While Henkel has seen success in its AI projects, any implementation of new technologies is not without its challenges. "One of the biggest issues is generating all of the relevant data for a process and its influencing environment, and making this information available for a 'big data' solution so it can be utilized to its full extent," explains Gudszend, adding that Henkel is deploying enhanced data-analytics platforms to better integrate data across its global supply-chain and operations networks. Even with the challenges, Sreekumar emphasizes that Henkel has realized many

AxiPolymer

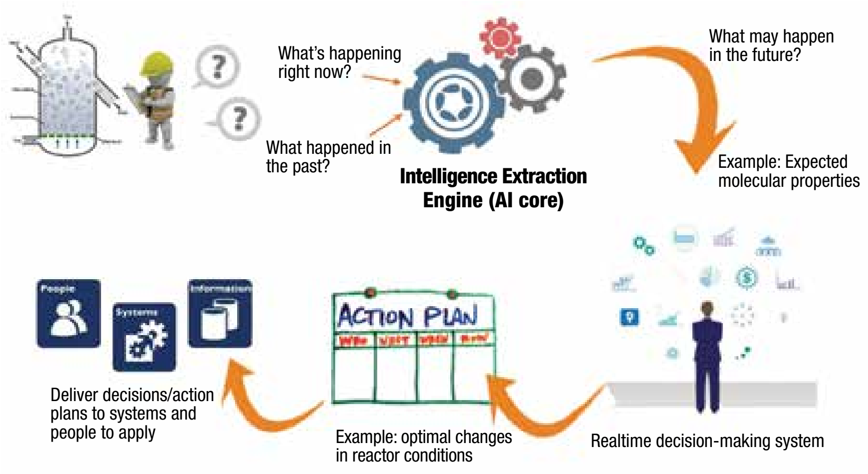


FIGURE 2. **New AI modules can consider the necessary process changes required to a system's current state to target a specific polymer property**

Cepsa

FIGURE 3. **Employing AI at this phenol plant effectively increased production capacity by over 5,000 metric tons per year**

AI benefits, from expediting speed to market for new product formulations and scaleup to rapidly detecting and resolving product-quality issues. "AI technologies are disruptive, and will continue to help drive new product launches and improve production rates from months and years to weeks or days. The technologies will encourage the development of new business models, improve operating conditions and generate better-quality products," he continues.

Accelerating product development

In Japan, a new research project has applied AI to significantly expedite polymer design and accelerate the development of advanced functional materials. The work done by Showa Denko K.K. (SDK; Tokyo; www.sdk.co.jp), the National Institute of Advanced Industrial Science and Technology (AIST; Tsukuba City; www.aist.go.jp) and the Research Association of High-Throughput Design and Development for Advanced Functional Materials (ADMAT; Tsukuba City; www.admat.or.jp) has indicated that AI-aided polymer design is about forty times faster than conventional ap-

Vopak

FIGURE 4. An automated inspection robot is prepared for deployment into an in-service storage tank

proaches. Beginning with a very large number of candidate polymers, the AI technology can predict polymer properties in less than one second per polymer, according to SDK. Current trials have focused on determining polymers' glass transition temperature from a field of 417 different types of polymer structural data, but the technology could easily be applied to any number of desired properties. In this case, the polymer with the highest glass-transition temperature was determined in just 4.6 trials (Figure 1).

This is not the first application of AI in the polymer-design sphere, but it is set apart by its use of Bayesian optimization, which further accelerates the process. "Usually, AI is not as efficient for polymer design because it tends to recommend similar polymers that have been previously examined. In contrast, Bayesian optimization enables us to survey a larger variety of polymers possessing a desired property by considering the tradeoff between high expected performance and high uncertainty," explains SDK. High uncertainty indicates that the polymer has not been examined in the past, and high performance indicates the polymer's appropriateness for meeting a set of property requirements. SDK believes that the high-speed prediction enabled by AI will provide a competitive advantage in the development of new products by evaluating a massive amount of candidate materials in a short amount of time without the need for manual experimentation.

AxiPolymer Inc. (Montreal, Que., Canada; www.axipolymer.com) has developed specialized AI solutions customized for the needs of polymer processors. "Polymer production, as well as polymer processing, have sophisticated interrelated parameters that determine the final polymer properties, and these parameters produce an enormous amount of data. AI provides us the opportunity to find the hidden pattern between these parameters to tailor final products' properties," says AxiPolymer. The company's experience with AI initially began with the development of decision-aid tools designed for implementation into polymer supply-chain processes. Then, based on additional analysis, the team began investigating the equipment failure and predictive maintenance needs of the industry using AI technology.

Since AI and machine learning are still relatively new concepts in the polymers industry, AxiPolymer observes that many companies are not aware of how deeply these tools can provide business competitiveness. "The main input for AI algorithms is historical data. In the polymer industry, the amount and variety of unprocessed data is incredibly high. It is clearly a matter of time until these tools become more commonly used to realize the full benefits of these data," explains AxiPolymer. AxiPolymer's R&D team is currently working on a novel, realtime decision-making module to provide AI-based optimization techniques for polymer producers and processors. Considering numerous control factors, such as reactor pressure, temperature and feedrate, as well as the impact of these parameters' variations on other properties, the module will enable users to predict and tailor final product properties without conventional trial-and-error development techniques. Moreover, according to AxiPolymer, the module can provide guidance on necessary changes in the current state of the system based on practical constraints to maintain the target properties of the final product (Figure 2).

In another project investigating AI for materials development, a team of researchers from Osaka University (www.osaka-u.ac.jp) applied AI to automate the selection of materials for organic photovoltaic (OPV) solar cells, which consist of an organic component and a semiconducting polymer. The work sought to maximize the power-conversion efficiency (PCE) of OPV cells by determining the optimal combination of organic and polymer materials, a process that typically requires a great deal of time-consuming trial-and-error experimentation. Using AI and machine learning, the team was able to evaluate data from 1,200 different OPV cells to target the optimal set of properties — in this case, band gap, molecular weight and chemical structure — to quickly determine which ones would be most efficient, and then screen polymers for their predicted PCE. The team then evaluated which of these resulting materials could most feasibly be manufactured. This particular work utilized "random forest" machine learning, which creates a network of decision trees for data classification and regression.

Enhancing operations and uptime

The promise of AI technologies in the CPI stretches beyond the laboratory — AI is positioned to transform operations through improved maintenance planning and process optimization.

In collaboration with SDK, Hitachi Ltd. (Tokyo; www.hitachi.com) has developed and commercialized an AI-assisted predictive-maintenance platform, which will now be offered to Hitachi's manufacturing customers worldwide. SDK's Oita Complex ethylene plant served as the trial facility for demonstrating the commercial practicality of the new AI service, which utilizes adaptive resonance theory (ART) to analyze and classify

Vopak

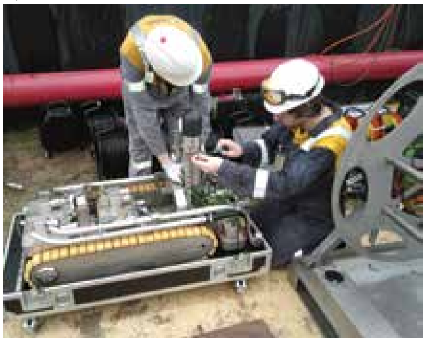


FIGURE 5. Drones, robots and advanced sensing and analysis platforms come together to improve safety and supply-chain management for storage terminals

plant operational data in realtime and identify anomalies that could lead to equipment failure. In trials at the Oita plant, the technology successfully predicted the occurrence of coking. According to Hitachi, this method is able to detect patterns and abnormalities that would not be detected by conventional predictive-maintenance models. Now, SDK plans to roll out the technology into additional plants, while also further refining the AI model for determining different coking mechanisms.

In December 2018, Compañía Española de Petróleos S.A.U. (Cepsa; Madrid, Spain; www.cepsa.com) completed a project to implement AI technologies to improve operations at its phenol production unit at the Palos chemical plant in Huelva, Spain (Figure 3). According to the company, these new AI-enabled measures have increased phenol production by 2.5%, resulting in an additional 5,500 metric tons of annual capacity. To achieve this, two realtime optimization routines were developed that use machine learning and predictive models to provide operational-improvement recommendations to plant personnel at 15-min intervals. Building these optimizers required analysis of over 3,000 process variables, ranging from laboratory data to local climate conditions.

In June 2018, Repsol (Madrid, Spain; www.repsol.com) launched a collaboration with Google Cloud to apply AI and advanced data analytics to optimize consumption of energy and other resources at Repsol's 186,000-bbl/d petroleum refinery in Tarragona, Spain. According to Repsol, the project aims to intelligently manage over 300 variables using various AI and machine-learning models, which represents a more than tenfold increase in the number of variables that are typically handled by digitally integrated industrial systems.

Safety and environmental upgrades

"Smart" sensors, AI and robotics are increasingly being employed to improve safety and resource efficiency. Storage tank and terminal operator Royal Vopak (Rotterdam, the Netherlands; www.vopak.com) is piloting several advanced technologies at its facilities in Singapore, including drones, robots and "intelligent" logistics and planning systems (Figure 4). "The use of robots for tank inspections avoids sending staff into confined spaces and minimizes the exposure of personnel to potentially hazardous conditions," says Edwin Ebrahimi, innovation engagement leader for Vopak Terminals Singapore. Furthermore, since tanks do not need to be cleaned and ventilated for in-service robotic inspections, generation of emissions and wastewater is avoided. During these in-service inspections, the tank remains available to customers. In addition to inspection robotics, the team is also evaluating condition monitoring and digitalized supply-chain integration as part of its Singapore innovation drive (Figure 5). "The Singapore terminals function as a testbed for new technology, and after successful trials here, we aim to deploy it throughout our network worldwide," explains Ebrahimi. Beyond analyzing and automating technical processes, the company is also seeing success in digitalizing administrative and logistical activities. "The use of RPA and AI will help us reduce the administrative workload of our logistics and operations departments, so they can focus on value-added tasks for our customers, creating better visibility on their supply chain. Finally, improving terminal productivity will lead to lower operational costs," says Ebrahimi.

AI also holds promise to streamline water-treatment operations. Two separate projects from the University of Waterloo (Ont., Canada; www.uwaterloo.ca) are using AI to tackle major water-treatment challenges — leakage and cyanobacteria. Working with industry partners, researchers from the university have developed a sophisticated AI signal-processing platform that uses hydrophone sensors to record acoustic signals to detect even very small leaks in water pipes. In laboratory trials, the sensors successfully detected leaks as small as 17 L/min, and researchers are now conducting field trials of the technology. The ability to quickly and accurately detect signs of leakage enables more proactive response.

The presence of cyanobacteria creates a variety of serious problems for water-treatment plants, and monitoring is crucial in mitigating these issues. AI software developed at the University of Waterloo can identify and quantify different varieties of cyanobacteria and provide automatic analysis of water samples in about 1–2 hours — considerably faster than traditional manual-analysis techniques that may require 1–2 days to complete. The quick analysis turnover can provide operators early warning of potential issues. The team's goal is to evolve the AI software into a microscopic continuous-monitoring solution to handle additional microorganisms and other contaminants beyond cyanobacteria.

Last month at the 2019 Consumer Electronics Show (CES) in Las Vegas, Nev., ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com) and IBM Q (www.ibm.com/ibmq), IBM's industry-first initiative focused on accelerating quantum technologies, announced a new partnership that will bring quantum computing capabilities into the energy sector for the first time. Quantum computing — an emerging technology with immense computational power — holds promise to tackle extremely complex scientific challenges more effectively than conventional computers. For ExxonMobil, potential applications of quantum computing include predictive environmental modeling and discovery of new materials for more efficient carbon capture.

While advanced technologies like quantum computing are still very new to the CPI, new applications will certainly continue to arise as more users begin to understand the capabilities of AI. ■

Mary Page Bailey

Protection Through Better Housekeeping Practices

Using the hierarchy of controls can help guide housekeeping and safety programs to better protect employees and facilities

There is a close link between safety and housekeeping for all manufacturers, but facilities that store, handle or process chemicals have an even greater responsibility when it comes to housekeeping and safety. Due to the nature of the materials being processed, industrial hygiene and safety practices must be top notch because they protect employees, communities and the environment from the substances used onsite. For this reason, it's important to employ typical housekeeping practices, such as spill cleanup, as well as necessary engineering controls, such as dust and fume collection and personal protective equipment (PPE).

"Safety and good housekeeping go hand in hand," says Dan Silver, vice president of product development with New Pig Corp. (Tipton, Pa.; www.newpig.com). "Having a clean, dry work space that's free of clutter reduces the chances of a workplace accident. Also, when working with chemicals, leaks, drips and spills are inevitable. Every facility should have a spill response program in place and trained responders with spill response kits ready. Good housekeeping practices like these mean employees can focus on their work without navigating through the landmines of clutter or potentially dangerous spills and debris," says Silver (Figure 1).

In specialized facilities, such as chemical processing plants, it is important to remember that safety, hygiene and housekeeping are intertwined, as safety is a discipline that is rooted in an organized and systematic approach to hazard and risk assessment, says Tim Zeh, safety director with Fisher Scientific (Pittsburgh, Pa.; www.fishersci.com). "With respect to chemicals, poor hygiene can elevate the risk of working with hazardous chemicals, whether in a laboratory or on a production scale," he says. "A major portion of the Occupational Safety and Health Administration's [OSHA; Washington, D.C.; www.osha.gov] Laboratory Standard (29 CFR 1910.1450) specifies the mandatory Chemical Hygiene program as an example of how important hygiene is as an underpinning to a safety program."

New Pig

FIGURE 1. When working with chemicals, leaks, drips and spills are inevitable, so every facility should have a spill response program in place and trained responders with spill response kits ready

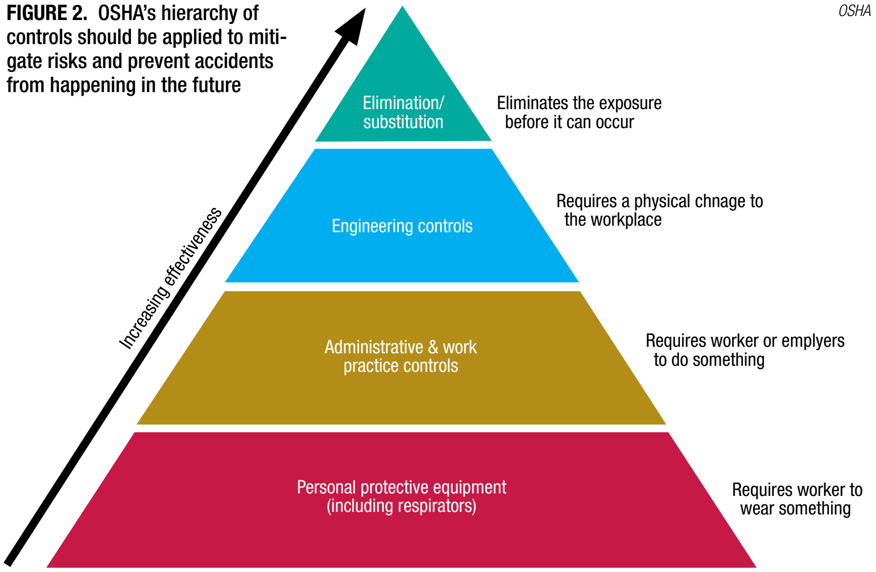
Zeh adds: "However, putting the system in place is only the first step, refresher training and updating programs are really the only way to maximize the effectiveness of the hygiene and housekeeping system."

So, how does a chemical processor determine what their safety, hygiene and housekeeping system should include? "Leading companies do not limit housekeeping to just general areas or have a one-size-fits-all approach," says Bob Balderson, senior manager, Corporate EHS at W.W. Grainger, Inc. (Lake Forest, Ill.; www.grainger.com). "They not only have practices in place for maintaining walking and working surface areas, but they also perform risk assessments on the specific type of operations and work practices onsite and, as a result, develop detailed, specific housekeeping practices, schedules and controls for those areas."

Risk assessment and hierarchy of controls

Mark Tartaglia, senior CIH consultant with DuPont Personal Protection (Wilmington, Del.; www.safespec.dupont.com), says the first step in creating a solid housekeeping, hygiene and safety plan is performing a hazard risk assessment as directed by OSHA and then applying the hierarchy of controls to each risk. "The employer must perform a hazard risk assessment that looks at particular tasks, activities and operations within the facility and evaluate each for all the potential hazards that exist in order for the worker to perform that work and then apply the hierarchy of controls to eliminate or reduce those risks."

FIGURE 2. OSHA's hierarchy of controls should be applied to mitigate risks and prevent accidents from happening in the future



According to OSHA, one of the root causes of workplace injuries, illnesses and incidents is the failure to identify or recognize hazards that are present or could have been anticipated. A critical element of any effective safety and health program is a proactive, ongoing process to identify and assess hazards. To do so, the agency suggests:

- Collecting information about present or likely to be present hazards
- Conducting inspections to identify new or recurring hazards
- Investigating injuries, illnesses, incidents and close calls to determine the underlying hazards, causes and safety and health program shortcomings
- Group similar incidents and identify trends
- Consider hazards associated with emergency situations
- Determine the severity and likelihood of incidents that could result for each hazard and use this information to prioritize corrective actions

Once a risk has been identified, it is suggested that OSHA's hierarchy of controls be applied to mitigate these risks and prevent accidents from happening in the future. The hierarchy of controls is a pyramid (Figure 2) with "elimination or substitution" at the top. This step aims to eliminate exposure before it occurs or substitute a less hazardous material in the process, requiring a permanent change to the process or job. "A good example of this would be in the paints and coatings industry where many manufacturers have made

RoboVent

FIGURE 3. An air-filtration system ducted to multiple hoods keeps air cleaner, employees safer and equipment well-maintained in this robotic welding space

the move away from solvent-based products to water-based," says Tartaglia. "This reduced the hazards by substituting a lower-hazard material in place of a higher hazard [one]."

The next step down the pyramid is "engineering controls," which requires a physical change to the workplace. An example would be vapor, dust or fume collection equipment to mitigate vapor, dust or fume dangers that range from annoyances to health hazards to explosion risks.

The third layer of the pyramid is "administrative and work practice controls," which requires implementing procedures that require a worker to do something to reduce the risk. An example would include being prepared for spills and having practices in place to handle anything from cleaning up a minor spill to handling a major hazardous spill incident.

Finally, "personal protective equipment," at the base of the pyramid, is considered "the last line of defense," according to Tartaglia. "Employers should depend on PPE after implementing other means of exposure controls in order to control residual risks." The necessary equipment will depend upon the risk, but may include eye and face protection, gloves, respirators and/or protective garments.

"A proper risk assessment helps develop an understanding of risks and exposures in the specific chemical processing work environment," says Grainger's Balderson. "Once risk is assessed, decisions can be made based on the hierarchy of controls: Can the hazard be eliminated altogether? Can you substitute the hazard? Can an engineering control be applied? Can administrative controls be developed and effective? And lastly, can PPE be used as a control? Many times it may be a combination of several control methods used, but having proper understanding of the risk involved is critical in selecting effective controls."

When considering the various controls and their application to support housekeeping and safety, there is an abundance of products on the market, says Balderson. Whether the controls are proper flooring selection, secondary containment systems, absorbent matting, spill response/containment kits or controls in the form of flammable and chemical storage cans, containers and cabinets or providing the correct PPE, the key to selecting an effective control is ensuring it addresses the specific risk within the operation as determined by the risk assessment. "One support resource is the suppliers and manufacturers of these equipment controls, as they have experts on staff to support chemical processing facilities with assessments and identify the appropriate controls specific to the work environment," he says.

While this article explores the importance of dust collection, spill control and containment, and PPE as they fit into the hierarchy of controls, remember every facility will have different and additional equipment and housekeeping needs based upon the specific risks found during the risk assessment.

Engineering controls

When elimination or substitution isn't an option, engineering controls become necessary. One of the biggest areas of concern for chemical processors is dust and fume collection as they pose risks ranging from slips and falls to illness to explosion.

Poor air quality can cause problems beyond inhalation risks, says Greg Carmichael, vice president of sales with RoboVent (Columbus, Ohio; www.robovent.com). Coolant mists create one of the greatest risks in a facility as they can accumulate on surfaces and cause slip-and-fall hazards. "Fortunately, specially designed air cleaners fitted with the right kind of filters can pull oil mists out of the air and prevent this problem."

Another major risk, says Carmichael, is that of explosions caused by combustible dust. When this dust combines with oxygen in a certain proportion, a single spark can cause it to explode. Exhausting or filtering these dusts is crucial to ensure that they don't accumulate in the air or on surfaces. Fire protection measures in the dust collection system can prevent sparks from penetrating the equipment or ductwork.

And, as all chemical processors know, chemical dusts carry special dangers for the employees who work with them, says Carmichael. Many have high concentrations of elements that are toxic in the body at certain concentrations. Other chemical dusts can react badly with body tissues or cause harm simply from accumulation (Figure 3).

The key to controlling dusts, mists and fumes is proper selection and installation of a dust or fume collection system, which includes a capture hood, piping and a collector that is specifically designed for the material being generated, says Curt Corum, sales manager with Air Handling Systems (Woodbridge, Conn.; airhand.com). "It's important to first define the contaminant and particle size and then look at the point of discharge. The first goal is always source cap-

ture — to go right after where the material is generated — and select a properly sized capture hood."

Next, according to the particle size, there are different air-speed requirements to convey material from point A to point B via proper piping systems and ductwork. Finally, the selected collection device must be appropriate to the size of the particle, type of material and potential hazards.

"The proper three are the key to safely collecting dusts and fumes in any facility," says Corum. "This means when hooding, piping and collection device are properly sized and engineered, it is possible to reduce hazards such as dust on the floor, health hazards or explosion hazards dramatically. Only in a perfect world do you get 100% of dust and fumes cleaned up, so for the remaining hazards there are self-contained air cleaners, as well as safety and housekeeping procedures to mitigate the remaining risk."

Corum continues to say that the importance of clean air is great. "Cleaning up dust and fumes must be a high priority for processors. You can have PPE, safety training and everything else, but if you don't clean up dust and fumes, you end up with sick people and explosion hazards. Once you control dust and fumes, all other safety items can fall into place around it."

Work practice controls

Since slips, trips and falls cost business and industry more than $11 billion per year [according to Liberty Mutual Workplace Safety Index], it's obvious that cleaning up leaks and spills is one area where proper work practices have a direct impact on safety, says Karen Hamel, regulatory compliance trainer with New Pig. "Using absorbent socks to surround a spill will keep liquid from spreading and turning a small problem into a bigger one. Once the spill is confined to one area, employees may be able to continue working safely while the spill is being cleaned up by spill responders. Using absorbent mat pads to clean up the contained liquid is much faster and easier than cleaning a spill with old-style loose clay-based absorbents."

Spill Tech

FIGURE 4. For the chemical industry, it is important to ensure that the chosen absorbent is compatible with the spilled material, which is where hazmat absorbents come in

Susan Naser, vice president of sales with Spill Tech (Johns Creek, Ga.; www.spilltech.com) agrees that absorbents are essential to keeping a facility safe from hazards associated with spills. "Just as there are paper towels in your kitchen because you know you're going to spill something, you have absorbents in your facility because you're going to spill something," she says. "For the chemical

Kafko

FIGURE 5. Whether it's a small spill in a facility or a tanker letting loose, being ready with the proper materials, such as absorbents and spill kits, and having a plan in place are key

DuPont

FIGURE 6. Chemical processing facilities often contain the full spectrum of hazards and therefore require the full spectrum of PPE available on site, including full protective suits, respirators, goggles, gloves, fall protection, electrical safety equipment and more

industry, this is especially important because there may be aggressive chemicals that can't be cleaned up with a wipe or a rag, so they typically need three types of absorbents on hand — oil only, universal and hazmat — and they need to ensure that the chosen absorbent is compatible with the spilled material, which is where hazmat absorbents shine" (Figure 4).

She says these are typically made of polypropylene, which is compatible with most chemicals, and they are yellow so employees know to use caution around this spill. "Yellow is the international color for hazmat. They are very high visibility, which reduces the risk of slip and fall and lets people know there is an aggressive chemical spill, so they need the right PPE or to call the proper department for spill response."

But in order for absorbents to do their job, there must be corporate commitment to safety that includes being prepared for spill response.

"Whether we are talking about small spills in a facility or a tanker letting loose, being ready with the proper materials and having a plan in place are key," says Rick Morgando, brand manager with Kafko (Skokie, Ill.; www.oileater.com) (Figure 5). "This ensures that when it happens, the plan is already in place and you are prepared. If you aren't ready, an accident can turn into catastrophe."

New Pig's Silver agrees: "Proactive planning impacts spill control by requiring facilities to create plans, procedures and tools that focus on keeping chemicals where they are supposed to be: in their containers, in pipelines or in process. Although the focus is on not having spills, it is irresponsible to think they will never occur, so proactive planning involves being prepared. This is where spill containment and spill response tools and procedures come into play."

Providing appropriate secondary containment or spill containment prevents spills from becoming releases. It buys the facility time to decide how best to handle the material that has spilled while it's confined to a predetermined area. Without secondary containment, spills can quickly escalate from an inconvenience to an emergency. They can also have much larger impacts on the safety of employees as well as the surrounding community, notes Silver.

Personnel protective equipment

Since PPE is the last line of defense, it's important for processors to know the two key PPE safety challenges: ensuring that the workforce has the proper PPE from head to toe to protect them from the chemicals they are working with or exposed to and, that in the event of an industrial spill or accident, the PPE will help mitigate injuries incurred from exposure to the chemical, says Fisher Scientific's Zeh.

"In my experience in the chemical industry, you see the full spectrum of hazards and typically need the full spectrum of PPE available on site, including full protective suits, respirators, goggles, gloves, fall protection, electrical safety equipment and so on," says DuPont's Tartaglia.

Chemical processors need to be especially careful that PPE such as gloves and garments are evaluated in terms of the materials' ability to hold out chemicals for both permeation and degradation, as well as how PPE is constructed (garment seam construction, glove length, surface texture, and so on) to ensure that PPE works as a full system, notes Zeh from Fisher Scientific.

To determine what you need, Tartaglia says, most manufacturers offer tools for employers to help them choose an appropriate option for gloves, garments, respirators and so on, based on the risks identified in their facilities and the chemicals to which personnel are exposed. For example, DuPont offers a web-based tool called SafeSPEC (www.safespec.dupont.com) that aids employers in the selection of protective garments (and soon gloves for a new product line that will be introduced this year) (Figure 6).

"The best options for PPE must be able to control exposures to acceptable levels and are considered the last option, since PPE requires user training, upkeep and are subject to human decisions on how effective they are," says Zeh.

While these options for housekeeping and personnel safety are just the tip of the iceberg of what is necessary and available, in all cases, better housekeeping in a chemical facility has the ability to help "protect what matters most" — your people, products and the environment, says Zeh. ■

Joy LePree

Focus on Filtration

The launch of a filter press and ceramic-disc filters

After a recent acquisition of Swedish filtration-technology company NovaTek, this company has introduced Flowrox Filter Press (FP) and Flowrox Ceramic Disc (CD) Filter (photo) to its product range for solid-liquid separation. Flowrox Filter Press (FP) has been developed together with filter operators and is especially well suited for material production applications. FP provides fully automatic operation, high-quality performance and high availability. The CD filter requires low investment and delivers clear filtrate with dry cake. Compared to conventional vacuum filters, it consumes approximately 90% less energy, says the company. The CD filter operates continuously with high capacity and is a cost-efficient solution for many concentrator and tailings processes. — *Flowrox Oy, Lappeenranta, Finland*
www.flowrox.com

Strainer and filtration solutions to match process needs

This company's diverse range of filtration solutions (photo) includes single, dual and multi-basket designs for pressures up to 50 bars; automatic and self-cleaning filters, back-flushing strainers and models in a full range of sizes up to 36 in. Standard, "commodity" models are complemented by fully engineered, customized solutions, fabricated to meet customer needs. In a range of materials, including cast iron, cast steel, stainless steel, duplex and super duplex, all are supported by experienced engineers, who help ensure customers get the right solution and support for their application throughout its lifetime. — *SPX Flow, Inc., Charlotte, N.C.*
www.spxflow.com

New vertical cartridge filter for industrial dust collection

The new Vertical Cartridge Filter (VCF; photo) removes industrial dust while incorporating a unique design for handling medium to high air volumes. The dust collector comes equipped with many time- and cost-saving features. An easy-to-use cartridge-clamp system simplifies replacement of the filter media, thereby minimizing maintenance time and lowering overall cost of operation. The filter is also equipped with a smart timer, which includes an onboard sensor that reads the pressure drop across the filtering elements for on-demand cleaning. This results in reduced compressed-air consumption and longer cartridge life. A standard radial inlet allows for excellent material separation during moderate air-volume applications, while the optional high-entry inlet with a pre-separation chamber is designed for optimal performance in high-volume systems. The chamber separates the largest powder particles, safeguarding the media from excess loads of pollutants and guaranteeing longer media life. — *Schenck Process Holding GmbH, Darmstadt, Germany*
www.schenckprocess.com

High-end cutting capabilities for filtration media

This company introduced the capability to cut many types of filtration media into various shapes and sizes to meet users' specifications. Filtration media includes activated carbon, 100% synthetic media, non-shedding polypropylene, coalescer media and more (photo). Typical applications for specially cut filtration media include industrial and automobile manufacturers, vacuum-cleaner manufacturers, electronics manufacturers, aerospace, medical and pharmaceutical facilities and other critical applications. — *Advanced Filtration Concepts, Inc., Norwalk, Conn.*
www.advfiltration.com

A new filtration-product line for electrocoat paint

This company recently launched a new line of Electrocoat (E-coat) paint spiral ultrafiltration membranes that offer manufacturers greater recovery of paint resin and pigments. The new

Flowrox

SPX Flow

Schenck Process Holding

Advanced Filtration Concepts

Note: For more information, circle the 3-digit number on p. 58, or use the website designation.

Porvair Filtration Group

Krohne

KPAK Plus and SpiraPAK Plus modules feature optimized element design and construction to improve performance while providing the same excellent separation properties and low fouling characteristics as the traditional KPAK and SpiraPAK modules. "With up to 20% higher productivity, these new products will benefit end users by improving paint yields and reducing overall operating costs," says Taylour Johnson, product manager of Industrial Processes. Benefits of ultrafiltration in the E-coat process include: the recovery of up to 98% of paint solids for reuse, while generating rinse water (permeate) for use in the plant; removal of excess free ions, low-molecular-weight resins and carry-in from pretreatment; recovery of up to 98% of dragged-out paint and reduced loading on wastewater treatment plants. — *Koch Membrane Systems, Inc., Wilmington, Mass.*
www.kochmembrane.com

A system to treat spent polish and alloy wastewater

Fully automatic with rolling casters for easy mobility, the LGEN-PAL is designed for all optical-lens-generating laboratories to easily treat spent polish and alloy wastewater all in one system. The LGEN-PAL reclaims clean water from both alloy water and spent polish together at the same time. The treatment allows thick, dry waste to be thrown away as a solid waste and clean water to be safely put down the drain. With the possibility of fines being imposed as high as $50,000 for improper disposal, optical laboratories need to safely treat their alloy and spent polish water. LGEN-PAL meets the demands of high-efficiency lens generation by safely removing waste. The LGEN-PAL system eliminates the high cost of outside source spent polish and alloy water removal. — *Filtertech, Inc., Manlius, N.Y.*
www.filtertech.com

A wide range of filters for compressed air applications

This company recently added the Compfil range of compressed-air filtration to its portfolio of liquid, air and gas filtration products (photo). The ISO-certified filters exhibit a range of different properties and are used within many industrial processes for the removal of particulate matter from compressed gas and air streams. There are five different filters available: Compfil DF filter, featuring a three-dimensional borosilicate depth media and achieving a void volume of 95%, ensuring a high containment capacity at high flowrates and low differential pressure; Compfil AC absolute-rated activated carbon filters, which are designed for the removal of oil vapor and other hydrocarbons; Compfil IA, which are high performance industrial air filters with nanotechnology that removes water and oil aerosols, as well as particulate matter from compressed air and gas; Compfil VY Polyethylene pre-filters, which are designed for particle retention from compressed air and gases down to 25 µm; and Compfil UF, which are high-performance depth filters, designed to remove water and oil aerosols, as well as particulate matter from compressed air and gas streams. Available alongside these filters are two types of housings: aluminum, with usage indicator, and stainless-steel options to cover both industrial and sterile filtration. — *Porvair Filtration Group Ltd., Fareham, Hampshire, U.K.*
www.porvairfiltration.com

A flowmeter for single-use biopharmaceutical processes

The Flexmag 4050 C (photo) is said to be the first electromagnetic flowmeter with biocompatible and disposable flow tubes specifically developed for single-use biopharmaceutical applications, including filtration processes, chromatography or buffer and media preparation. Featuring extremely high accuracy and factory calibration that eliminates the need for in-situ calibration, the Flexmag 4050 C includes a biocompatible and gamma-sterilizable disposable flow tube. All wetted materials comply with FDA/USP Class VI and ISO 10993, and are manufactured in an ISO 13485 certified site within an ISO 7 clean-room environment. The Flexmag 4050 C flow tube uses a single-barb fitting that meets biopharmaceutical requirements for adaptation to single-use systems. The single-barb fitting is suitable for braided and non-braided hoses. — *Krohne, Inc., Peabody, Mass.*
www.us.krohne.com

Gerald Ondrey

Drones

Autonomous inventory management for stockpiles

This company has launched an inventory-management solution (photo) for mining and aggregates companies to reconcile drone surveys with data from enterprise resource planning (ERP) and other systems of record for production and sales data. Bringing together drone-based topographic surveys, cloud-based analytics and inventory-management capabilities provides a single source of data to streamline operations. Included are capabilities to track specific products across multiple production sites, enabling users to more efficiently plan production and logistics for high-demand materials by identifying discrepancies in inventory data faster to avoid costly issues, such as overproduction. Teams in multiple locations can benefit from visibility into site-wide materials, enabling transparency across operations, sales, surveyors, engineers and management. Autonomous, on-demand drone flights over stockpiles reduce reliance on third-party or manual measurement and can provide volume calculations within 1–3% of true volume, says the company. Furthermore, drones can help to visualize the calculated base plane in three dimensions to ensure volumetric quality assurance and verify elevation changes and measure linear distances all from a single workspace. — *Kespry, Menlo Park, Calif.*

www.kespry.com

A compact drone equipped with geofencing safety capabilities

The PD6B-Type II (photo) is a large-platform aerial drone equipped with a geofence system and a built-in safety unit. When deviating from flight safety range or altitude, it is possible to self-activate a parachute to make the drone land safely. The PD6B-Type II comes with a maximum payload of 30 kg (66.1 lb) in a compact design that make it easy to carry and deliver. It adopts a layout in which the propeller does not wrap when spreading by reversing the mounting direction of the adjacent motor. As a result, the distance between the shafts is shorter than the previous six-rotor machine. The overall height is 550 mm and the machine weighs just 11.5 kg. The PD6B-Type II's smooth flight and interchangeable battery packs makes it possible to acquire survey data using laser sensors with high precision. The drone's maximum speed is 60 km/h and it can operate in wind speeds up to 10 m/s (22.4 mph). — *ProDrone Inc., Mountain View, Calif.*

www.prodrone.com

New software applies machine learning to drone imagery

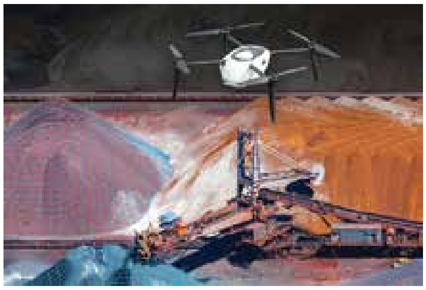
Map Engine (photo) is a new machine-learning-driven photogrammetry software that generates high-resolution maps and 3-D models from drone imagery. The new processing engine leverages the latest cloud infrastructure and machine-learning technology to deliver high-quality results and help users reduce hardware and maintenance costs, says the company. The new Map Engine release now generates maps and models 30–50% faster than previous versions of the software, says the developer. Scenes made up of hundreds of images can be processed in under an hour. Mobile-upload capabilities enable users to wirelessly transfer images to the cloud. — *DroneDeploy, San Francisco, Calif.*

www.dronedeploy.com

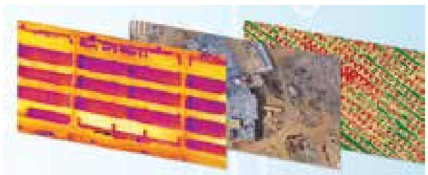
A full suite of autonomous inspection and testing services

This company's inspection platform involves automated testing services with robotic crawlers, unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs), combining advanced predictive analytics, digital-inspection data warehousing and intelligent inspection-planning recommendations. Using aerial, ground and underwater sensors attached to robots

Kespry



ProDrone



DroneDeploy

Note: For more information, circle the 3-digit number on p. 58, or use the website designation.

Intelligent Energy

Topcon Positioning Group

Scentroid

to collect vital inspection data and recommend targeted, risk-based inspection scheduling and planning, the Avitas cloud-based inspection platform centralizes and stores the data, allowing for archival searches of inspection records. 3-D modeling software allows for targeted robotic paths that can be repeated to detect asset changes over time. Inspection data from both manual and autonomous inspection can be combined with asset-performance data, external data sources (such as climate conditions) and new inputs from subsequent inspections. Advanced algorithms automatically detect asset defects and anomalies, and as more data are ingested across diverse sources, the deep-learning models, stored on the company's AI Workbench, retrain for smarter actionable insights. — *Avitas Systems, a GE Venture, Boston, Mass.*
www.avitas-systems.com

Modular fuel-cell technology enables longer drone flights

The lightweight 650W fuel-cell power module (FCPM; photo) has been specifically designed for the commercial drone market and offers considerably longer flight time when compared to traditional batteries. Flight time is one of the key pain points for commercial drone operations. Key benefits of the 650W FCPM include increased productivity, less downtime owing to quick refueling and increased payload capability. The FCPM can be used as a standalone product, or combined with another module to provide up to 1.3 kW of power. The FCC-compliant product is commercially available and is suitable for a variety of unmanned aerial vehicles, including multi-rotor and fixed-wing. The module runs on hydrogen and ambient air to produce clean power in a simple, cost effective, robust and lightweight package. It can be integrated into UAV platforms without compromising payload, according to the manufacturer. — *Intelligent Energy Ltd., Leicestershire, U.K.*
www.intelligent-energy.com

Software for navigating aerial inspection data

Magnet Inspect (photo) is a new software designed to facilitate data processing workflow for UAV-aided inspection. The software efficiently manages large UAV data sets to create inspection reports. Compatible with models from virtually any UAV, the software enables operators to efficiently navigate, annotate and create reports with inspection photos, creating an end-to-end inspection workflow. Magnet Inspect is designed to allow operators to visually navigate UAV photos, aligning 3-D reality meshes with raw georeferenced images in one location and filtering them based on selected criteria, including field of view. Images from the inspection can be flagged to indicate whether there are issues, and annotated with built-in free-hand graphical tools. — *Topcon Positioning Group, Livermore, Calif.*
www.topconpositioning.com

Safer air sampling for accurate emissions monitoring

The DR300 Flying Laboratory (photo) is a sampling drone that can be used to sample ambient air at heights of up to 125 m above ground level or directly sample from stack plumes. Height sampling and direct plume sampling can be used to increase accuracy of emissions assessments. When using the DR300 sampling drone, operators can stay safely away from hazardous sources while acquiring environmental samples. The DR300 can be flown into the plume of a flare to take direct samples to analyze chemical composition. Temperature and humidity of the plume are also measured for dispersion calculations. DR300 air-sampling drones provide remote monitoring of more than 50 chemicals. Data from onboard sensors are transmitted to an operator's tablet for live viewing and logging. The DR300 kit includes the drone itself, along with a remote controller, standing legs, sampling probe, three custom-made sampling bags, a set of spare rotor blades, a battery charger and spare battery pack and more. The sampling drone can be operated in temperatures up to 70°C. According to the company, it is possible to sample from a source under negative pressure. — *Scentroid, a Division of IDES Canada, Stouffville, Ont., Canada*
www.scentroid.com ■

Mary Page Bailey

This radar level sensor makes cryogenic applications secure

This company's 80-GHz radar sensors (photo) are temperature-decoupled from the process, meaning that they are optimized for the extreme process temperatures that occur in liquefied natural gas (LNG) and liquefied propane gas (LPG) applications, and easily withstand temperatures as low as –196°C. Ice does not form on the housing, nor is there any condensation on the antenna system. In addition to cryogenic applications, the specially protected housing and front-flush antenna cover constructed of polytetrafluoroethylene (PTFE) are also suitable for reliable measurement of aggressive media, including acids, alkalis or abrasive substances. — *VEGA Grieshaber KG, Schiltach, Germany*
www.vega.com

This benchtop spray dryer expedites materials testing

The PolarDry Model 0.1 electrostatic spray dryer (photo) retains the features of larger dryers in a much more compact footprint. The dryer can be easily disassembled for autoclave sterilization. By producing small-scale samples with minimum product loss, the Model 0.1 allows for greater feasibility testing of expensive materials. The smaller dimensions allow the Model 0.1 to fit inside small spaces, such as laboratory fume or containment hoods, where noxious solvents, potent active ingredients and oxygen-sensitive materials can be safely tested. As a result, research of new products is more efficient and cost-effective, says the company. The Model 0.1 is compatible with optional high-temperature and ultrasonic spray-drying nozzles for reliable microencapsulation. The ultrasonic nozzle is particularly suited for creating small particles less than 10 µm in diameter. — *Fluid Air, A division of Spraying Systems Co., Aurora, Ill.*
www.fluidairinc.com

A high-performance bead mill for high viscous products

The Visconomic+ high-performance bead mill (photo) was developed specifically for processing very viscous and temperature-sensitive products. The rotor and stator configuration maximizes cooling-surface exchange, resulting in a high cooling capacity. This enables the temperature of the product to be regulated during the grinding process so that excessive temperature increase is effectively avoided. As the product is well-cooled even with a higher power input, better dispersion quality can be achieved. The system's optimized grinding-gap width and the aggressive pin arrangement enable high throughputs, and optimum grinding results are achieved even with very viscous products. The grinding media are separated via a dynamic separating gap. Due to the constant shear in the gap, no particles can settle, which increases process reliability. — *Bühler AG, Uzwil, Switzerland*
www.buhlergroup.com

Simulate piping systems with this updated software tool

AFT Impulse 7 software (photo), a dynamic simulation and analysis tool used to calculate pressure-surge transients in liquid piping systems caused by waterhammer, has been recently updated with over 50 new and enhanced features. Users can create models using an isometric grid and utilize color animation to visualize parameter changes over time. Furthermore, the user interface for defining centrifugal and positive-displacement pump data has been improved, and functionality for calculating buried-pipe wave speed and modeling of pumps as turbines (PAT) has been added. Extensive new Excel capabilities include the ability to export output data and even complete exports while running batch scenarios. — *Applied Flow Technology, Colorado Springs, Colo.*
www.aft.com

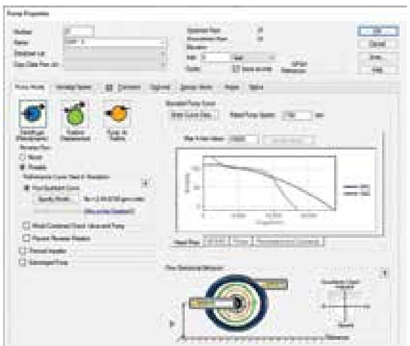
Use this handheld manometer in a wide range of pressures

DM 9600 Series precision manometers feature a color touchscreen and are designed with technicians in mind to provide data quickly and easily for startup, troubleshooting and reporting jobs for measuring pressure, temperature, flow and other parameters. Five different ranges are available from

VEGA

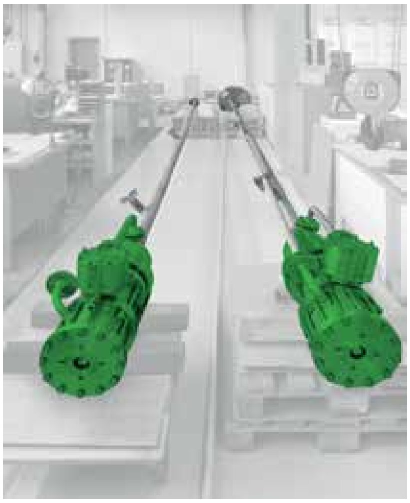
Fluid Air

Bühler



Applied Flow Technology

Hermetic-Pumpen



Siemens

Griswold

Phoenix Contact

±30 in. H_2O to ±100 psi. The low-pressure version is ideally suited for heating, ventilation and air conditioning (HVAC) applications, and the high-pressure versions can be utilized in a wide variety of industrial settings. Key features include 0.5% accuracy, flow calculations, dual thermocouple and outputs via micro SD card, USB and Bluetooth communications. Users will benefit from the conveniences of a magnetic back for hands-free use and the long-life (20-h) lithium-ion battery. — *MRU Instruments, Humble, Tex.*
www.mru-instruments.com

These long submersible pumps are hermetically sealed

Two of this company's eight-stage, sealless canned-motor pumps from the TCAM 30/4+4 series (photo) have recently been supplied as a replacement for conventional submersible pumps. The pumps are designed for easy installation in an existing tank. The supplied submersible pumps are the longest pumps that this company has ever produced, with an immersion depth of more than 15 m, and a pump shaft of only 1 m. The submersible pumps, in tandem design, convey the medium (NH_3) at a temperature of –33°C, with a delivery head of 260 m at a flowrate of 12 m^3/h. The pump units are designed for a nominal pressure of 40 bars. The drive unit's hermetically sealed design enables complete immersion in the vessel or tank. Only the discharge pipe and the electrical connection are routed through the tank cover via the manhole plate and out of the vessel. — *Hermetic-Pumpen GmbH, Gundelfingen, Germany*
www.hermetic-pumpen.com

Compact level transmitter with intelligent processing

The Sitrans Probe LU240 (photo) is this company's newest ultrasonic level-measurement HART transmitter. Field-proven echo processing separates true material-level echoes from false, providing reliable readings while still allowing rapid response to actual changes in the material level. The device's reduced blanking distance decreases waste in applications while boosting asset utilization by providing continuously accurate readings, even with high levels of material. For those applications requiring process temperature data, the Sitrans Probe LU240 now provides users both level and temperature readings. In dirty applications or those with buildup, the transmitter's maintenance-free active-face technology keeps the sensor clean and is also unaffected by wind, rain, snow or temperature changes. For rugged applications in harsh environments, it is IP68 fully potted and encapsulated with a polyvinylidene difluoride (PVDF) sensor that is resistant to corrosion, chemicals and extreme shock. — *Siemens AG, Munich, Germany*
www.siemens.com

Predictive maintenance improves pump diagnostics

SafeGuard (photo) is a predictive maintenance solution featuring wireless access and proactive alerts for all types of centrifugal pumps. SafeGuard allows both the pump and the motor to be remotely monitored at all times with continuous cloud connectivity. If an issue occurs, a proactive alert is automatically generated, which includes clear actionable guidance that can be easily followed by maintenance personnel to resolve the root cause of the issue. Four battery-powered sensors are included in the SafeGuard system, as well as a node/sensor reader. All four sensors work in unison to predict the full health of both the pump and the motor. This allows for a complete diagnostic analysis that reads the tri-axial vibration, temperature and electromagnetic values for the pump and motor. With these capabilities, SafeGuard is able to detect more than 20 failure modes. — *Griswold, part of PSG, a Dover Company, Grand Terrace, Calif.*
www.griswoldpump.com

A new safety controller with programming flexibility

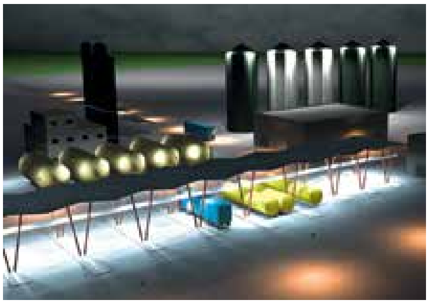
The Phoenix PLCnext Control RFC 4072S controller (photo) is the first high-performance controller for this company's PLCnext Technology ecosystem. It can be used to leverage all the advantages of the control platform: programming in users' preferred programming language and programming environment, using open-source software, apps, Proficloud and soon, the realtime version of the PLCnext store. In addition to a high-performance Intel i5 dual-core processor, the controller also

includes 4 GB of RAM. The safety-relevant calculations are performed by two independent CPUs that are based on different architectures. Therefore, it is suitable for applications with high safety requirements in accordance with SIL 3 or PLe. The safety-oriented controller uses the current Profisafe profile 2.61 for Profinet and Profisafe systems. — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.de

Lighting design for calculated efficiency

This company offers customized, optimized concepts for illuminating workspaces in accordance with EN 12464-1/-2, focused particularly on providing expertise in the switch to energy-efficient LED technology. The design includes all the relevant parameters and follows strict requirements as set out in the workplace directive, including illuminance, luminous efficacy and beam angle for uniform, glare-free illumination, as well as the correlated color temperature. The number, position and orientation of light fittings can be precisely matched to the room geometry, as well as the user's requirements and behavior. Solutions can be developed for a single workplace, as well as for large-scale emergency lighting systems and safety lighting. Proprietary, in-house-developed 3-D models (photo) are used to visualize the position and size of walls, fittings, fixtures, furnishings and any other equipment, and to simulate shadows and reflections. These models can then be rendered to generate photorealistic images. — *R. Stahl AG, Waldenburg, Germany*
www.r-stahl.com

R. Stahl



A next-generation purge and pressurization system

Designed for Class I or II/Div. 2 and Zone 2/22 locations, the 7500 series Ex pzc/Type Z purge and pressurization system purges a common enclosure of hazardous gas or dust to maintain positive pressure. With operations in fully automatic or manual modes, it effectively reduces the classification within the protected enclosure to a non-hazardous area. The 7500 carries ATEX and IECEx certifications and is UL listed. It operates within a very small footprint of 5.8 in. × 3.8 in. × 1.9 in. The 7500 Series includes intelligent automatic monitoring and control of enclosure pressure with dilution and continuous-flow functionality. The system makes automatic adjustments and provides an alarm output for reliable protection. It is designed in marine-grade chromate aluminum, making it rugged enough to withstand harsh conditions. — *Pepperl+Fuchs GmbH, Mannheim, Germany*
www.pepperl-fuchs.com ■

Mary Page Bailey and Gerald Ondrey

Pump Sizing Parameters

Department Editor: Scott Jenkins

A solid grasp of pump sizing allows engineers to make effective economic and practical decisions about process pumps. This one-page reference provides information about two key parameters and other considerations for pump sizing.

Pump sizing steps

Sizing a pump requires engineers to estimate the temperature, density, viscosity and vapor pressure of the fluid being pumped. Pump sizing can be accomplished in six general steps:

1. Find the total dynamic head (TDH), which is a function of the four key parameters of a pumping system, shown in Figure 1.
2. Correct for the viscosity of the fluid, since pump charts and data are given for water with a viscosity of 1 cP. Viscosity of other process fluids can differ dramatically.
3. Calculate the net positive suction head (NPSH) to select a pump that will not undergo cavitation.
4. Check the value of suction-specific speed to see if a commercial pump is readily available.
5. Check for potentially suitable pumps using a composite performance curve and an individual pump performance curve.
6. Compare the energy consumption and lifecycle cost of operating the selected pumps.

Total dynamic head

A key parameter in characterizing a pump is the total dynamic head (TDH), which is the difference between the dynamic pressure of the discharge side (after the pump) and the suction side (before the pump). Dynamic pressure represents the energy required to do the following: (1) to raise the liquid level from the suction tank to the discharge tank; (2) to provide liquid velocity inside both suction and discharge piping; (3) to overcome frictional losses in both suction and discharge piping; and (4) to pump the liquid against the pressure difference between the suction and discharge tanks.

To find TDH, the difference between the discharge velocity head (h_D) and the suction velocity head (h_S) needs to be calculated.

$$TDH = h_D - h_S \qquad (1)$$

$$h_D = D + \frac{v_d^2}{2 \times g} + h_{d,f} + P_d \qquad (2)$$

$$h_s = S - \frac{v_s^2}{2{\times}g} - h_{s,f} + P_s \qquad (3)$$

$$P\,(ft) = P(psi) \times \frac{2.31}{sp.gr.} \qquad (4)$$

TDH depends on the elevation difference between the discharge and suction tanks. In Equations (2) and (3), P is the pressure of the suction or discharge side, converted to units of length using the specific gravity of the fluid as in Equation (4). The TDH represents the difference between Equations (2) and (3), in which users actually add together the velocity head and the frictional head loss for both the suction and discharge sides of the pump.

Pumps must overcome the frictional losses of the fluid in order for the fluid to flow in the suction and discharge lines. Frictional losses depend on pipe roughness, as well as valves, fittings, pipe contractions, enlargements, pipe length, flowrate and liquid viscosity. To calculate the frictional head losses, in feet of liquid being pumped, on the suction ($h_{s,f}$) and discharge ($h_{d,f}$) side of the pump, Equation (5) can be used. The same equation can be applied to calculate the frictional losses of the discharge side, but with the appropriate values correlating to the discharge side of the pump.

$$h_{s,f} = 12 \times f_D \left(\frac{L}{I.D.}\right) \times \left(\frac{v^2}{2{\times}g}\right) + \frac{v^2}{2{\times}g} \sum_i^N (n_i \times k_i) \qquad (5)$$

Net positive suction head

NPSH is the net pressure available for pump suction after all deductions, such as line losses and vapor pressure, are taken into account. It is the pressure available in excess over the vapor pressure to prevent the pumping fluid from boiling. The aim with NPSH is to provide an adequate amount of head that exceeds the fluid's vapor pressure to prevent the fluid from boiling at the pump inlet. This excess head is defined as NPSH.

The NPSH value is used in the determination of whether the liquid on the suction side of the selected pump will vaporize at the pumping temperature, thus causing cavitation and rendering the pump inoperable. NPSH varies with impeller speed and flowrate. The following data are required for NPSH calculations.

Site atmospheric pressure. NPSH calculations are impacted by the site's local atmospheric pressure. This value is used in NPSH calculations, and the higher the atmospheric pressure, the better, with regard to NPSH.

Suction piping layout. The physical layout of the suction piping is important in determining NPSH. This must include the exact number of pipe fittings in order to properly determine the suction-piping pressure drop.

Vapor pressure of the pumping fluid. Vapor pressure depends on operating temperature. Vapor pressure for pure substances can be found in literature, such as "Perry's Chemical Engineers' Handbook." To determine the vapor pressure, the operating temperature must be provided.

Suction vessel elevation and operating pressure. The elevation of the suction vessel itself is also important. Additionally, the operating pressure of the suction vessel must be known. ■

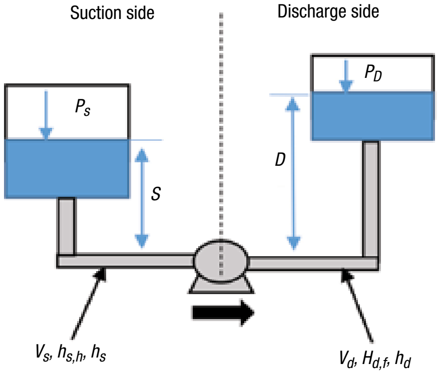


FIGURE 1. The following parameters are needed to calculate total dynamic head: suction and discharge elevation (S and D); fluid velocity (V_s and V_d); friction loss ($h_{s,h}$ and $H_{d,f}$) and dynamic head (h_d and h_s); and tank pressure (P_s and P_D)

Editor's note: This column is adapted from the following articles: Sarver, J., Finkenauer, B., and Liu, Y.A., Pump Sizing and Selection Made Easy, *Chem. Eng.*, January 2018, pp. 34–43; and Raza, A., Calculate NPSH with Confidence, *Chem. Eng.*, September 2015, pp. 46–51.

Oxygen Production via Cryogenic Distillation

By Intratec Solutions

Oxygen is a nonmetallic element and one of the most abundant elements on Earth's surface. Under standard pressure and temperature conditions, oxygen is a diatomic gas with the molecular formula O_2. The gas is used in several industries, including steel-making, chemicals, wastewater treatment, pulp and paper manufacturing, and others.

The process

The following paragraphs describe a process for oxygen production based on cryogenic distillation. Figure 1 presents a simplified flow diagram for the process.

Feed preparation. Initially, atmospheric air is passed through a mechanical air filter to remove dust particles, and compressed to a pressure of about 6 bars. The compressed air is fed to a direct-contact cooler, where it is cooled first with cooling water and then with chilled water. Subsequently, the cooled, compressed air is passed through an adsorbent bed of molecular sieves for the removal of water, carbon dioxide and other trace impurities.

Cryogenic separation. Purified air is then cooled down to nearly liquefaction temperature by means of expansion and heat exchange into a plate-fin heat exchanger (the main heat exchanger) in counterflow against cold nitrogen and oxygen product streams.

Gaseous and liquid air streams from the main heat exchanger are fed to the high-pressure (HP) column, the first of two distillation columns whose purposes are to separate an oxygen-enriched liquid stream from nitrogen. The product from the HP column overhead, consisting of pure nitrogen vapor, is condensed in the reboiler of a second distillation column downstream, operating at lower pressures (the low-pressure (LP) column), and used as reflux for both the HP column and LP columns.

The bottom product from the HP column, a liquid stream rich in oxygen, is split into two streams: part is fed into the LP column, while the remaining amount is routed to the combined evaporator-condenser of the argon column, where it is evaporated and subsequently sent to the LP column.

The LP column overhead, consisting primarily of nitrogen with traces of argon, is fed to the main heat exchanger, where it is warmed by heat exchange against purified air and subsequently compressed. The stream composed of high-purity oxygen, obtained as the LP column bottom, is compressed and vaporized by heat exchange against purified air in the main heat exchanger, and is then routed to nearby consumers via pipeline.

A side-stream rich in argon is withdrawn from the LP column and directed to a column where it is purified from most of the argon and returned to the LP column.

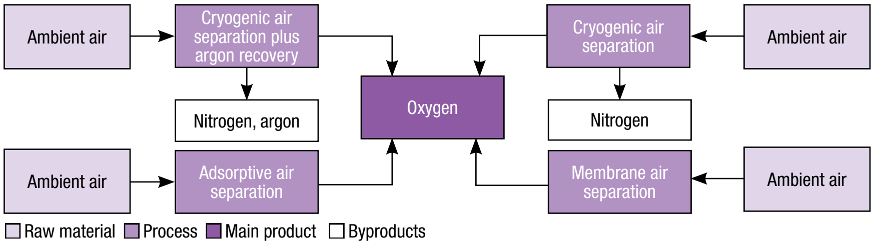


FIGURE 2. Several variations exist for oxygen production

Production pathways

Oxygen can be commercially separated from atmospheric air, via cryogenic distillation and adsorptive separation (vacuum-swing adsorption processes) (Figure 2).

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce industrial oxygen was about \$0.03 per normal cubic meter of oxygen in the first quarter of 2015, including credits associated with sale of nitrogen byproduct. The analysis was based on a large-scale plant constructed in the U.S. with the capacity to produce 3,000 tons per day of O_2.

This column is based on "Oxygen Production – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/oxygen-production-cost. ■

Edited by Scott Jenkins

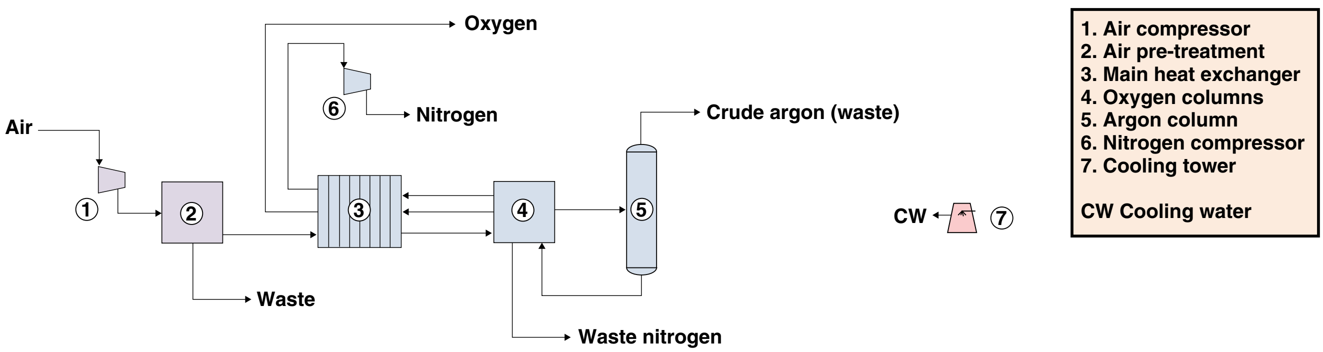


FIGURE 1. The diagram shows a process for oxygen production via cryogenic distillation

Boost Steam-System Efficiency by Improving Condensate Recovery

Pressurized condensate-return systems and flash-steam vent condensers offer opportunities for fuel cost savings in a plant's steam system. Here's how to take advantage

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Pressurized steam-condensate systems can provide plants with a minimum of between 15 and 35% savings in fuel costs when compared to conventional atmospherically vented steam-condensate systems. That is a tremendous opportunity for chemical process industries (CPI) facilities, since fuel prices have risen and are expected to increase even further. The pressurized condensate system should not be thought of as a luxury; rather, it should be considered a necessary component to maximize and increase the efficiency of a plant's steam system (Figure 1).

FIGURE 1. Pressurized condensate tank systems, like the one shown here, can help maximize efficiency in a plant's steam generation

Unfortunately, it is not possible to implement high-pressure condensate return systems for all steam plants and all steam applications (see box, p. 37). Therefore, proper preliminary engineering assessment, design review and knowledge of the application are necessary to ensure a successful condensate system. In the examples discussed in this article, energy savings of $226,700 were achieved by implementing a 50-psig pressurized steam-condensate system. The project was implemented at a cost of $305,400, yielding a 1.3-year payback.

This article provides information on pressurized condensate systems and explains how to evaluate whether the technology could be a cost saver at your plant.

Pressurized condensate recovery

Pressurized condensate recovery systems operate continuously at pressures above 15 psig, and the condensate recovery system is not vented to the atmosphere. The pressure in the condensate system is sustained by the dynamics of the system or by a systematic control process loop. Typical condensate systems operate with backpressure because their condensate line is improperly sized for two-phase flow and because plants often neglect steam-trap stations blowing steam into the condensate line. These items alone can cause unwanted and uncontrollable pressure in the condensate recovery system.

A pressurized condensate-recovery sys-

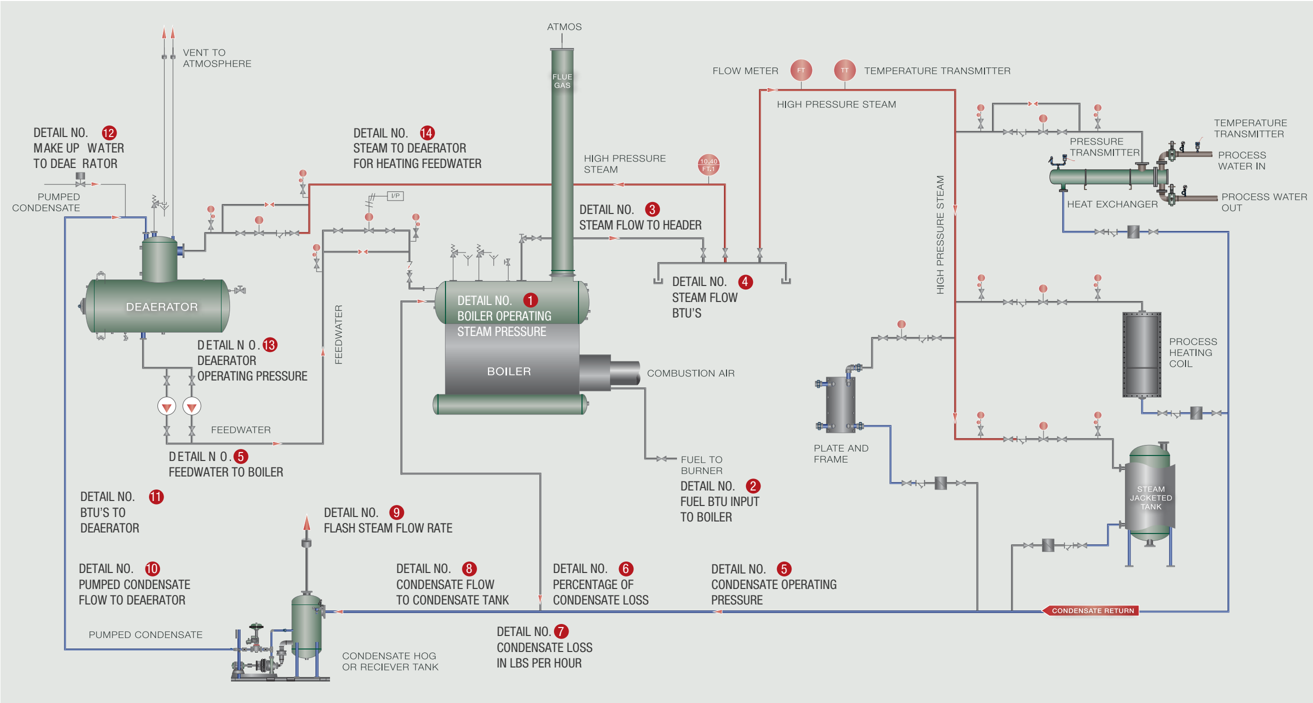


FIGURE 2. The diagram shows the layout of an atmospheric condensate system. Detail No. 9 shows where vented steam is lost

tem differs in that the condensate-return-line pressure is systematically controlled and managed to a predetermined set point that matches the peak performance level of the steam system process and integrates into the dynamics of the steam balance.

Four classifications of condensate systems are used in plants today:

1. Gravity or atmospheric condensate system (condensate line pressure is maintained at or close to 0 psig)
2. Low pressure (1 to 15 psig)
3. Medium pressure (16 to 99 psig)
4. High pressure (100 psig or higher)

Pressurized condensate system technology is not new in the steam world. These systems can be documented back to 1941. Though the technology may be considered old, it has been overlooked over the years due to relatively inexpensive fuel prices. As fuel prices have risen and, with them, the need for optimization to reduce overall operational costs, industrial plants are paying more attention to pressurized condensate systems, because they have proven to be a significant way to decrease expenses. In fact, these systems are considered to be among the top three items for optimizing a steam system, and have a very attractive payback for the investment. Figure 2 shows a steam system with atmospheric venting, while Figure 3 shows the same steam system with a pressurized flash-recovery line to the deaerator.

Increase efficiency and reduce costs

The best reason to use a pressurized condensate system is the remarkable energy savings that plants can often achieve with a low implementation cost. Any condensate that is not contaminated in a process application needs to be returned to the boiler to complete the steam system's thermal cycle and increase efficiency. Steam condensate contains a high quantity of sensible energy. If the sensible energy is not properly returned to the boiler operation, a large percentage, if not all, of this energy is lost.

Condensate that is returned to the boiler operation will require the condensate temperature to be raised to the saturated temperature of the steam boiler's operating pressure. To accomplish this task, energy is introduced at the deaerator and the boiler. The deaerator will add energy to heat the condensate to a temperature where non-condensable gases will be removed from the fluid. The boiler will add the energy for a phase change to occur at the boiler operating pressure.

The higher the temperature or pressure (direct relationship in steam) of the condensate being returned to the boiler plant, the less energy that is required to raise the temperature of the condensate back to the saturated temperature of the boiler operating pressure.

Theoretically, the most efficient system would be a condensate return system controlled at a pressure as close to the boiler operating pressure as possible. In a perfect system, the steam system would operate at 150 psi, and the pressurized condensate

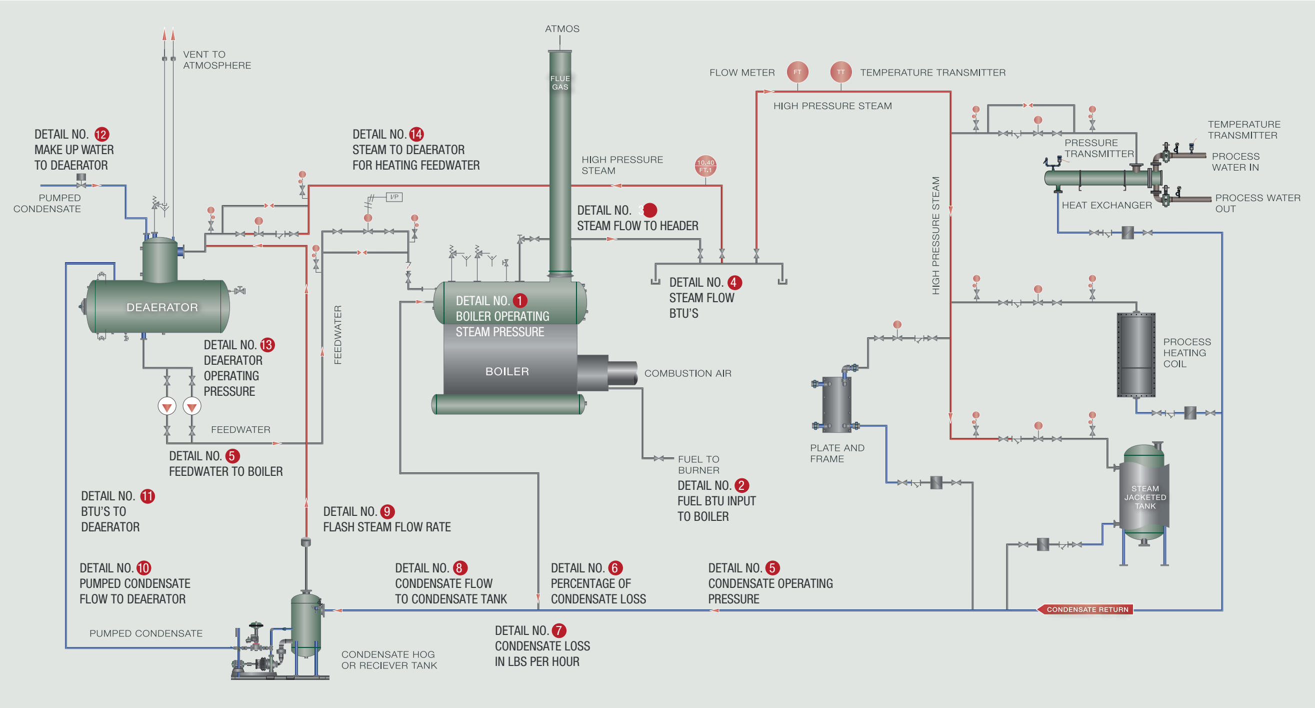


FIGURE 3. A pressurized condensate return is shown in this diagram. The flash steam at detail No. 9 is delivered to the deaerator

system would operate at 149 psi. However, the limitation is the type of steam and condensate system. The plant must consider elements such as line sizes, distances, steam-trap station differential and elevations. With these variables in the system, a typical target for the pressure differential between the steam supply and condensate

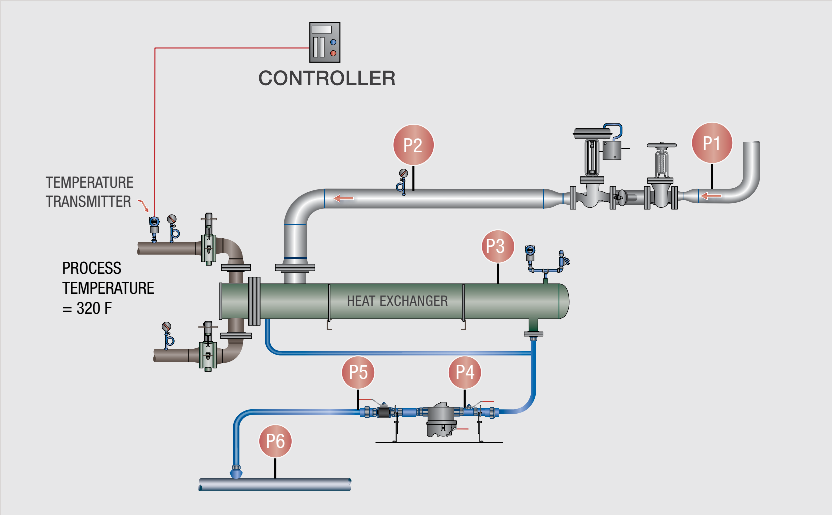


FIGURE 4. This diagram shows the high-temperature process outlet temperature at 320˚F

return is between 30 and 45%. All pressurized condensate systems must be thoroughly evaluated before selecting the condensate return-line pressure.

To determine the cost savings of a standard condensate system versus a pressurized condensate system, it is important to review all operational parameters. Figures 2 and 3 both show the following elements of the steam and condensate system:

- Detail 1: Boiler operating steam pressure
- Detail 2: Fuel input into the boiler, Btus
- Detail 3: Steam flow output from the boiler, Btus
- Detail 4: Steam flow, Btus
- Detail 5: Condensate system operating pressure
- Detail 6: Percentage of condensate loss
- Detail 7: Condensate loss, lb/h
- Detail 8: Condensate flow to tank, lb/h
- Detail 9: Flash steam flowrate, lb/h
- Detail 10: Pumped condensate to deaerator
- Detail 11: Condensate Btus to deaerator
- Detail 12: Makeup water flowrate to deaerator
- Detail 13: Deaerator operating pressure
- Detail 14: Steam flow to deaerator for heating feedwater

Standard condensate-return system

A standard condensate system, where condensate is recovered into an atmospheric condensate tank system, will have inherent energy losses. These energy losses include the following:

- Condensate is allowed to cool to 212°F
- A large amount of flash steam is generated
- Flash steam is allowed to escape to the atmosphere
- Flash steam losses increase the quantity of makeup water required

All condensate and makeup water, which will become boiler feedwater, will require energy input to bring the energy level up to the saturated temperature of the boiler operating pressure. Reducing the differential energy levels (condensate and makeup water) to the boiler saturated energy level will increase the steam system's thermal cycle efficiency.

Steam process conditions

Table 1 shows values for an example steam application in a process plant. A steam requirement for the process application is rated at 24,000 lb/h (provides 24,000 lb/h of condensate). Condensate is drained from the steam process through a standard steam-trap station. The steam trap station discharges condensate into a vented condensate receiver system. When condensate is drained from the process at a

TABLE 1. DETAILS OF A TYPICAL STEAM APPLICATION IN A PROCESS PLANT

Application	Steam process
Steam pressure supplied to the process	150 psi (before a control valve) equivalent
Steam temperature	366°F
Steam pressure at the process	150 psi pressure
Steam flowrate	24,000 lb/h (minimum)
Operation	8,760 h/yr
Condensate line pressure	0 psig (vented to the atmosphere and mechanically pumped back to the boiler plant)
Cost of steam (per thousand pounds)	$5.24

TABLE 2. SUMMARY OF ENERGY LOSSES IN A TYPICAL VENTED CONDENSATE-RETURN SYSTEM

Summary of operational costs	
Boiler fuel cost (yearly)	$1,167,301
Flash steam losses	$162,043
Steam for deaerator operation	$64,657
Total energy loss cost	$226,700
The atmospheric system has a total energy loss of $226,700/yr as a result of flash steam loss, deaerator steam requirements to heat the low-temperature and makeup water, in addition to the cost of additional chemicals.	

WHEN PRESSURIZED CONDENSATE RECOVERY IS NOT POSSIBLE: VENT CONDENSERS FOR FLASH-STEAM RECOVERY ON MODULATING STEAM SYSTEMS

The operational design of modulating steam systems requires the condensate to be recovered by a gravity (0 psig) condensate system, so pressurized condensate recovery is not an option. In these cases, a typical system will incorporate a condensate receiver that allows the flash steam to vent to the atmosphere. The venting of the flash steam ensures the condensate receiver is never pressurized. The use of vent condensers for flash-steam recovery in modulated steam systems is described below.

Flash-steam recovery in modulating steam conditions

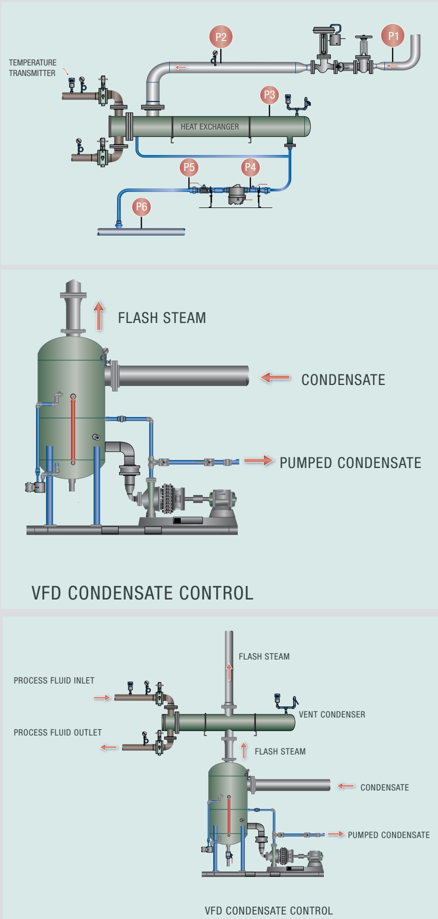
With today's energy pricing and the need to reduce emissions, a plant's steam/condensate systems cannot afford to vent flash steam to the atmosphere. To prevent the flash steam loss to the atmosphere, plants can install devices, such as flash-steam vent condensers in the flash-steam vent line.

Depending on the installation costs, plants can usually recover the cost of a flash-steam vent condenser within ten operational months.

There are two main cost-saving benefits for a flash-steam vent condenser: it allows a plant to recover the flash-steam energy, which can be used to heat a fluid for a process; and it reduces emissions by recovering the flash-steam energy. The boilers will not have to produce as much steam, thereby lowering emissions from the boiler operation.

When condensate and flash steam (two-phase flow) is discharged from a modulating steam/condensate process, it means the process application has a steam-control valve that modulates the steam to the process. The control valve can operate from 0% (full closed) to 100% (full open) and anywhere in between (Figure 5, top diagram) The steam pressure after the steam-control valve and before the process heat exchanger can vary (P2 reading) depending on process conditions. The pressure at P2 can range from the full line pressure being delivered to the steam control valve (P1) all the way down to zero pressure.

In this case, the flash steam cannot be recovered in a pressurized flash tank, or a high-pressure condensate-return system. Instead, the condensate flow from the process has to be discharged into a condensate line with pressure at 0 psig (P5) and delivered to a vented condensate receiver tank that is operating at or close to zero pressure.



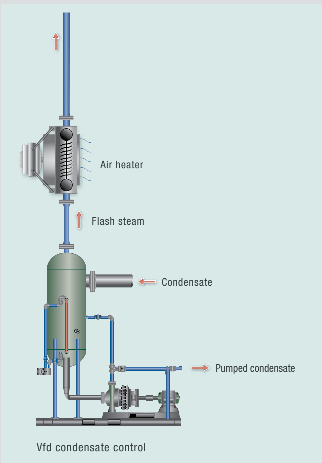


FIGURE 5. A modulated steam-condensate process has a control valve (top) and a receiver tank vented to the atmosphere (upper middle). A flash-steam condenser (lower middle) can be used to heat air (bottom)

Flash-steam vent condenser operation

The upper middle diagram of Figure 5 depicts the typical condensate-receiver-tank arrangement, where the flash steam is allowed to be vented to the atmosphere. The energy loss and emission factors today permit this loss in the system.

A flash-steam vent condenser is incorporated into the system to recover the flash steam by using an external heat exchanger (condenser), as shown in the lower middle diagram. The vent condenser (heat exchanger) will consume the flash steam by heating air, water or some other process fluids. The vent condenser is designed for the application to ensure proper operation. A standard shell-and-tube heat exchanger functions in this application. The process fluid consumes the flash steam and allows the condensate to drain back into the condensate tank. Therefore, the flash steam is consumed and the condensate is recovered. In the case of a modulating-steam process condition, the process steam system should use the lowest steam pressure, therefore producing the least amount of flash steam possible.

The shell-and-tube heat exchanger designed for a condenser applications is the typical heat-transfer design used in flash steam condensers. Other heat exchanger units that can be used are spiral, plate-and-frame, and fin-coil units (heating units for air or process gases). Materials and installation considerations will vary depending on the application. All vented condensers are engineered for the application.

Fluid for the condenser. To condense the flash steam, the condenser requires a fluid temperature of less than 160°F (general consideration). The fluid can be a liquid or vapor, depending on the application. If there is an insufficient quantity of cooling fluid for the flash steam in a liquid cooling system, then the plant should consider using a flash-steam bypass or some other method to prevent the cooling liquid from absorbing too much energy and changing from a liquid to a vapor and causing water hammer.

Heating air is another application for a vent condenser. The bottom diagram in Figure 5 shows the air passed over a tube fin configuration with the flash steam inside the tube. The lower temperature air condenses the flash steam, and the condensate is allowed to drain back into the condensate tank.

Pressure on the condensate tank. When choosing a vent condenser, the plant must select a design that does not create significant pressure for the condensate receiver tank. The flash steam vent line from the condensate tank to the condensing unit velocities should not exceed 900 ft/min.

Required information. For successful vent-condenser purchase, installation and operation, operators should know the following parameters:

1. Condensate flowrate (maximum, minimum and normal)
2. Flash steam flowrate (maximum, minimum and normal)
3. Cooling fluid flowrate (maximum, minimum and normal)

Before installing a condensate tank with a vent condenser, first locate and document the different flash-steam vent lines that are discharging to the atmosphere. Next, determine the flash steam lost to the atmosphere. Then calculate the projected energy loss and emissions reductions and determine what types of cooling fluids are available ❑

TABLE 3. STANDARD VENTED CONDENSATE SYSTEM OPERATING AT ATMOSPHERIC CONDITIONS			
EXAMPLE 1: OPERATION AT ATMOSPHERIC CONDITIONS			
Detail 1: Boiler operating at steam pressure (psig)	150	Total cost of producing steam at flowrate	$1,102,658.20
Detail 2: Fuel input to boiler: Btus required to produce steam	28,703,191	Detail 3: Steam flow (lb/h)	24,000
Cost of steam per thousand lb	$5.24	Hours of operation/yr	8,760
Btus (per lb): Total at 150 psig	1,196	Btus latent (per lb): Steam energy at 150 psig	857
Btus sensible (per lb): Condensate at 150 psig	339	Cost per Btu	$0.00000439
		Detail 4: Total Btus to process	28,703,191
Detail 5: Condensate line operating pressure	0	Btus (per lb) steam at 0 psig	970
Percentage of flash steam	16.3%	Btus (per lb) condensate at 0 psig	180
Detail 6: Percentage of condensate loss	10%	Btus (per lb) total Btus at 0 psig	1,150
Detail 7: Condensate loss (lb/h)	2,400	Detail 8: Condensate flow to condensate tank	21,600
Detail 9: Flash steam flowrate (lb/h)	3,527	Detail 10: Condensate flow rate (lb/h)	18,073
Detail 11: Condensate Btus to deaerator	3,255,814	Detail 12: Makeup water flow rate (lb/h)	5,927
Detail 13: Sensible energy in deaerator at operating pressure	208	Makeup water Btu requirement to achieve deaerator sensible energy level	877,191
Detail 15: Btus to increase condensate to deaerator operating pressure	503,378	Total Btu requirement for deaerator	1,380,568
Steam flow to deaerator	1,407	Cost of steam for deaerator	$64,657.45
Btus in the boiler operation to produce steam at operating pressure	988	Total Btu requirement for boiler fuel per year	207,710,033,609
Cost of fuel per decatherm	$4.30	Boiler efficiency	81%
Yearly boiler operating cost	$1,102,658.20		

given pressure (150 psi) and passes through a steam trap station to a lower pressure (0 psi at 212°F), then a percentage of the condensate will flash to steam. The vented condensate receiver tank allows the flash steam to be vented to the atmosphere and ultimately leads to a loss of energy, and the flash steam loss will increase the quantity of make-up water. The condensate is allowed to be reduced to 212°F, which will require an influx of energy at the deaerator and boiler to achieve phase change at 150 psig. The deaerator will use essential steam (steam off the main header) to heat the low-temperature condensate and make-up water up to the operating saturated conditions of the deaerator operating pressure.

Implementing pressurized systems

Quantifying the losses in terms of money is the first step to developing an improvement plan (Table 2). Pressurized condensate systems are an excellent method for reducing these losses by 75% or more, depending on the existing operating conditions of the steam and condensate system. Understanding the dynamics of the current system as well as the dynamics of implementing a pressurized system will lead to successful implementation.

In a pressurized condensate system, typical losses will be greatly reduced or eliminated by the dynamics of the pressurized system. Pressurized systems have several benefits, as follows:

1. The pressurized system will increase the condensate temperature or sensible energy level. The condensate temperature in the pressurized system is now at the temperature of the deaerator or higher. Therefore, the deaerator does not require essential steam (energy) to heat the condensate, saving essential steam.
2. Another benefit to pressurized condensate is that condensate has not been exposed to the atmosphere and has not absorbed any noncondensable gases. The condensate does not have to go through the deaerator process. In several types of installations, the condensate can be delivered directly into the boiler.
3. It will reduce makeup water usage. With the flash steam being recovered in a pressurized system, no flash steam is lost. Thus, the only need for makeup water is to replenish the deaerator's noncondensable vent losses. The makeup costs are negligible in a pressurized system. Reducing makeup water also will reduce boiler blowdown, thus reducing another energy loss in the boiler operation.
4. It will reduce the flash steam quantity that is generated, which will reduce the condensate pipe sizing requirements and re-

Before changing an industrial steam system into a pressurized condensate system, the first step is to ensure that the steam/condensate system and the steam processes will be able to operate under the new conditions

duce the condensate losses (1 lb of flash steam is 1 lb of condensate).

5. It will reduce the energy differential (condensate versus boiler operating condition). This will reduce the amount of fuel input into the boiler to raise the feedwater to the appropriate phase-change temperature.
6. It will enable the plant to use the flash steam from a pressurized system.

Before changing an industrial steam system into a pressurized condensate system, the first step is to ensure that the steam/condensate system and the steam processes will be able to operate under the new conditions. Condensate and flash steam (two-phase flow) discharging from a non-modulating or elevated-temperature process can operate in a pressurized condensate system.

A non-modulating steam condition refers to a steam system process where no control valve modulates the steam flow into the process to maintain a desired temperature or pressure. A process steam system that lacks a modulating steam-control scheme for the process provides a constant steam pressure to the process. Therefore, if the condensate recovery system has a controlled pressure, there is a constant pressure differential across the steam trap stations or condensate discharge control valve.

In a high-temperature process where the process temperature is higher than the pressurized condensate system, there will be differential pressure across the drain devices, such as the steam trap station or condensate discharge control valve. For example, as shown in Figure 4, if the process temperature

TABLE 4. SAME STEAM SYSTEM AS SHOWN IN TABLE 3, BUT OPERATING WITH A PRESSURIZED CONDENSATE SYSTEM: STEAM PRODUCTION COST IS REDUCED			
EXAMPLE 1: OPERATION WITH PRESSURIZED CONDENSATE SYSTEM			
Detail 1: Boiler operating at steam pressure (psig)	150	Total cost of producing steam at flowrate	$940,600.59
Detail 2: Fuel input to boiler: Btus required to produce steam	28,703,191	Detail 3: Steam flow (lb/h)	24,000
Cost of steam per thousand pounds	$4.81	Hours of operation per year	8,760
Btus (per lb): Total at 150 psig	1,196	Btus latent (per lb): Steam energy at 150 psig	857
Btus sensible (per lb): Condensate at 150 psig	339	Cost per Btu	$0.00000402
Steam flow from the boiler (deaerator and process)		Detail 4: Total Btus to process	28,703,191
Detail 5: Condensate line operating pressure	50	Btus (per lb) steam at 50 psig	912
Percentage of flash steam	7.8%	Btus (per lb) condensate at 50 psig	267
Detail 6: Percentage of condensate loss	10%	Btus (per lb) total Btus at 50 psig	1,179
Detail 7: Condensate loss (lb/h)	2,400	Detail 8: Condensate flow to condensate tank	21,600
Detail 9: Flash steam flowrate (lb/h)	1,687	Detail 10: Condensate flowrate (lb/h)	19,913
Detail 11: Condensate Btus to deaerator	5,323,644	Detail 12: Makeup water flowrate (lb/h)	4,087
Detail 13: Sensible energy in deaerator at operating pressure	267	Makeup water Btu requirement to achieve deaerator sensible energy level	604,841
Detail 15: Btus to increase condensate to deaerator operating pressure	0	Total Btu requirement for deaerator	604,841
Steam flow to deaerator	656	Cost of steam for deaerator	$0.00
Btus in the boiler operation to produce steam at operating pressure	929	Total Btu requirement for boiler fuel per year	181,579,443,953
Cost of fuel per decatherm	$4.30	Boiler efficiency	83.0%
Yearly boiler operating cost	$940,600.59		

is at 320°F, steam pressure to the process has to be higher than 75 psig. With steam pressure of 75 psig to the heat exchanger, P4 (in the example) will have a pressure of 70 psig or greater, and the condensate line pressure could operate at 30 psig.

Here are some examples of steam systems and processes that may be candidates for pressurized condensate return setups:

- Steam tracing
- Process ovens
- Process heating systems
- Steam line condensate removal steam trap stations
- Paper machines
- Rubber processes
- Press operations
- Reboilers
- Corrugators

Energy savings

Using the same example of an atmospheric condensate system and implementing a pressurized condensate system (increase the condensate pressure to 50 psig), the optimization results are as follows:

- Boiler fuel cost (yearly): $1,167,301 versus $940,601
- Flash steam losses: $162,043 versus $0.00
- Steam for deaerator operation: $64,657 versus $0.00

Implementation of a condensate system that is operating at 50 psig instead of 0 psig resulted in a savings of $226,700.

The new pressurized condensate system now operates as follows:

1. Condensate line now operates at 50 psig
2. Flash is operating at 50 psig with the flash steam going to the deaerator
3. Deaerator is operating at 50 psig
4. Condensate is directed to the storage side of the deaerator
5. The steam system is balanced and the steam-system thermal cycle efficiency is increased

Tables 3 and 4 provide details of the steam production costs and savings for pressurized condensate-return system (Table 4) versus the atmospherically vented system (Table 3).

Components required

Several components are required to implement a pressurized condensate system.

Pressure control system. A pressure control system controls the condensate pressure to a predetermined set point. The condensate pressure must be managed. One method is to use a backpressure control valve with a controller. An easier method is to use a flash tank discharging into the

steam system that has a controlled steam pressure.

Flash tank or deaerator. Installing a flash tank system that delivers flash steam to a controlled steam system is an excellent way to operate the pressurized condensate system. One user of flash steam is the deaerator, which normally operates below 15 psig. Most steam systems have several operating steam pressures, so the flash steam can accept the cascaded steam.

Another method uses a thermocompressor to raise the flash steam's pressure and reintroduce it into the steam processes or deliver the steam into a plant steam-system, pressure-distribution system. Installing a new deaerator or using the current deaerator, which can operate at a higher pressure, is a third method of receiving the pressurized condensate. The deaerator is operated at a predetermined operating pressure that is the same as the pressure in the pressurized condensate system. The condensate temperature is already elevated, and there will be a reduced quantity of flash steam, which is normally consumed by heating the makeup water.

Pressurized condensate. Pressurized condensate does not have to be deaerated and can be pumped directly back into the boiler. Since the condensate has not been exposed to the atmosphere, it has not had the opportunity to take up any noncondensable gases.

Condensate-line sizing. Condensate-line sizing always needs to be checked to ensure that it has the proper design to operate in a pressurized operation. Typically, the condensate-line size required is reduced by the lower quantity of flash steam, which normally requires more area in atmospheric or very low-operating-pressure condensate lines. Velocities are also reduced due to the lower flash-steam quantity, thus eliminating the normal water-hammer issues with high condensate-line velocities.

Getting started

There are many reasons to implement a pressurized condensate system, if it is possible to do so, and little to no downside. The first step in moving toward this technology is for plant personnel or an outside firm experienced in pressurized condensate systems to conduct a steam and condensate assessment. The assessment will provide the knowledge of the benefits of pressurized condensate system and, more importantly, the cost of implementation. ■

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Air Coolers Versus Shell-and-Tube Water Coolers

As shown here, economical cooling is often achieved with a combination of both air and water cooling. Design considerations are also presented here

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For the last 40 years, air-cooled heat exchangers have become an indispensable part of many chemical, petroleum-refining, petrochemical, gas processing and power plants, as well as off-shore platforms. In locations such as the Middle East, where the availability of cooling water is limited and expensive, air-cooled exchangers may be a preferred choice. However, even there, due to various process constraints, air cooling alone may not always suffice, so water cooling may also be required.

Similarly, where cooling water is plentiful, shell-and-tube coolers may not always be a straightforward solution. Due to the need for elaborate cooling-water piping circuits, a cooling tower, large cooling-water circulation pumps and water-conditioning systems, the complexity and capital requirements are generally very high, leading to a preference for air coolers over shell-and-tube coolers. In this article, with the help of a case study, the author discusses situations where the combination of both air cooler and water coolers can be used, including considerations for better overall project economics.

TABLE 1. PERFORMANCE COMPARISON IN AIR COOLER

Particulars	Air in counter-current to process fluid in finned tube (Step 1)	Air in co-current to process fluid in finned tube (Step 2)	Air in co-current to process fluid in bare tube(Step 3)
No. bays/No. of bundles	4/ 4 × 2	5/ 5 × 2	8/8 × 1
No. of tube passes/No. of rows	12/8	12/8	16/8
Heat Duty, MW	12.4	12.4	12.4
MTD, °C	67.6	57.4	64
Hydrocarbon velocity, m/s	0.65	0.47	0.41
Surface area requirement, m^2	2,808 (bare), 35,354 (finned)	3,670 (bare), 46,201 (finned)	5490
Hydrocarbon NRE, in/out	3,376–301	2,411–222	3,300–200
Tube skin Temp, °C	50.6	61.5	61.5
Exchanger cost, million $ (approximate)	0.8	1.0	Not estimated
Installation cost, million $ (approximate)	0.63	0.8	Not estimated
Operating cost, million $ (approximate)	0.24	0.3	Not estimated
Total cost, million $ (approximate)	1.67	2.1	Not estimated

Why use air coolers?

Even though overall economics play a major role, an air-cooled heat exchanger is used extensively in all kinds of on-shore plants and off-shore platforms as a first choice of cooling mechanism for one of the following reasons:

Total installed cost (TIC). The TIC of an air-cooling system is less than that of a cooling water system. Due to lower thermal conductivity and specific heat of air compared to water, the heat-transfer coefficient will be about one third that of a water-cooled exchanger, leading to higher heat-transfer area in air coolers. In addition, an air cooler requires elaborate structures, which further increases fixed costs by anywhere from three to ten times that of a shell-and-tube water cooler, depending on materials of construction. Nevertheless, an air cooler is usually preferred to avoid, completely or partially, the requirement of elaborate cooling-water piping circuits, cooling tower, cooling-water circulation pumps and water-conditioning systems and so on, because such additional equipment incurs much larger fixed costs. In addition to that, the operating cost of pumping raw water, make-up water and power for cooling-tower fans makes the TIC of water-cooling system much higher than an air-cooling system, which only requires operating costs for the fan power and some controls, such as variable frequency drive, louver and so on (see the case study, below).

Fouling. The costs associated with fouling are usually lower for air cooling compared to water cooling. Shell-and-tube coolers, the cooling-tower basin and other peripheral equipment require regular maintenance due to extensive fouling and scaling, and also biological treatment is required, without which the performance of the operating plant drops substantially due to deposition or fouling in the shell-and-tube coolers. Air coolers may also become fouled on the outside due to the accumulation of dust, insects and other debris on the finned surface, but less maintenance is required to handle this. Where shell-and-tube overhead condensers or trim condensers are used for cooling or condensing column overhead vapor, any drop in performance due to fouling can mean loss in processing material (hydrocarbon, chemical) and thermal energy. As a result, the column pressure can be affected and the hydrocarbon material is lost in slop, or flared, or the production of lower-grade material.

Flexibility. An air cooler offers more flexibility for controlling the process-fluid outlet temperature. There are various ways to safe energy by controlling the process-fluid outlet temperature in an air cooler, as follows (see also the case study below):

- Switching one fan off during winter months or during the night time
- Using variable-speed drive motors having 10–100% operable range
- Using auto variable-pitch fans where blade angles change to draw more or less air (power)

Such operational flexibility is nonexistent in shell-and-tube coolers, as rarely any control is provided for the cooling water side of water coolers.

Location. No specific location is required for air coolers. However, any process plant that uses a shell-and-tube cooler together with a water-cooling system will be preferred when the location is near a source of water, such as river, lake or the sea.

Power. In the event of a power failure, cooling can continue in an air cooler by natural convection. When fan motors fail to run due to mechanical or electrical problems, an air cooler can still provide cooling of 10–15% of the design heat duty by natural convection. Loss of power or other mechanical issues in a shell-and-tube cooler can cause the water to be heated up more than the desired outlet temperature, causing scaling and fouling.

Why shell-and-tube coolers?

Cooling range. Air coolers can be used mostly as primary coolers for process fluid that requires cooling before storage. If a process fluid is to be cooled or condensed from 100°C or above, to 45°C or below, an air cooler can first cool the process fluid down to 65–70°C, then further cooling is provided by a shell-and-tube water-trim cooler for final cooling before it proceeds for rundown or storage. A shell-and-tube cooler or condenser may not be a direct choice due to the probability of high tube-skin temperature, which can lead to scaling in the tubes. Where process cooling is in a lower range (70–45°C) obviously air coolers cannot be used at all, and shell-and-tube water coolers are the only choice.

Approach temperature. Shell-and-tube water coolers can accept a lower approach temperature. For an air cooler, an economical approach temperature between the outlet of process fluid and the ambient air temperature is generally 15–25°C, whereas for shell-and-tube water coolers, the approach temperature can be as low as 5°C.

Winterization. In cold climates, air coolers require extensive winterization arrangements to protect against congealing (due to low pour point of process fluid) or freezing for very low air-inlet design temperature. Elaborate ducting with louvers, actuators, steam coil or heating fans under each fan can increase the capital cost many times. In shell-and-tube water coolers, simply switching the cooling medium to a tempered water system can prevent freezing of the process fluid.

Plot areas. Air coolers require a large plot area due to the larger heat-transfer area requirement. In contrast, a shell-and-tube cooler is very compact and requires much less space.

Location and performance. The performance of air coolers is affected by the proximity of other structures. The efficiency of air coolers goes down drastically when the wind direction changes seasonally, affecting air inlet temperature to the bundles due to the presence of furnace stack, columns and other equipment in the path of the changing air-flow direction. Because these equipment cannot be positioned very far from other structures due to space constraints in the operating plant, the air temperature may increase by few degrees. Also, if sufficient space is not allocated between air coolers and columns, furnaces and buildings in the same unit, hot-air dispersion gets hampered, leading to hot-air recirculating to the fresh intake air. This lowers the mean temperature difference (MTD), and the area for cooling becomes inadequate.

Maintenance. Air coolers generally have higher maintenance requirements than shell-and-tube condensers. An air cooler consists of many static and rotating components that may have maintenance issues, such as: 1) fan-shaft misalignment, leading to high fan/motor vibration which stops fan; 2) high fan/motor bearing temperature, resulting in failure of coupling

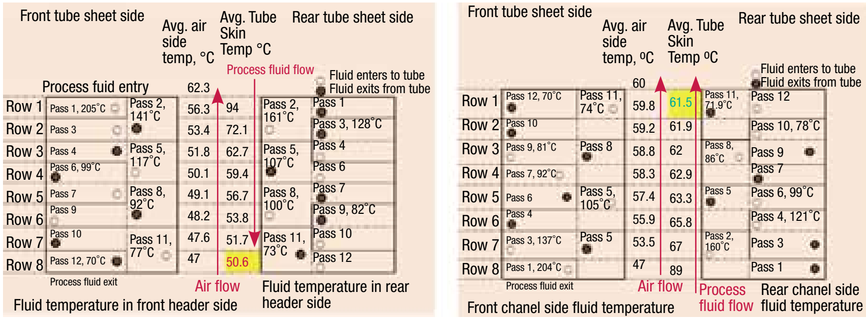

FIGURE 1. As seen by these two examples, the tube skin temperature in an air cooler is linked to the direction of the air flow

and belt; 3) dust/debris/pollen built up on tubes, leading to increased air pressure drop in the bundle and reduction of airflow (some reverse flow also can be seen) leading to loss in cooling capacity; 4) corrosion of finned tubes due to salty atmosphere or mishandling by water washing and so on; 5) breakage or stuck louver or the failure of the louver positioner, causing restriction in air flow and reduction of cooling capacity; and 6) mal-operation of auto-variable pitch fan blades, as they can get stuck and then air flow cannot be adjusted by variable-blade pitch angle.

Case study

As an example, we discuss the challenges in handling a high-viscosity, high-fouling and low-pour-point hydrocarbon in an air cooler.

A residue-upgrading project in a petroleum refinery has a backwash oil cooler where hydrocarbon is cooled from 204 to 70°C. The oil viscosity is in the range of 1.4 to 40 cP and the pour point is 38°C. In this project, the engineer has restricted the Reynolds number to a minimum of 2,000. The design ambient-air temperature is 47°C. The location of the refinery does not require extensive winterization for such a liquid.

The design target for handling high-viscosity, high-fouling and congealing (low pour point) hydrocarbon is to achieve a tube skin temperature of at least 15°C above pour point, maximizing the tube velocity and the heat-transfer coefficient such that the Reynolds number lies in the turbulent region.

To get a reasonably high velocity in the tube side for such fluid requires increasing the number of tube passes in a deep bundle of 8 to 12 rows. But this also leads to a higher tube-side pressure drop, which can be justified economically because the increase in the operating and capital cost of the pump is small compared to surface area and cost of air cooler saved. In general, this design has a relatively higher surface area requirement. Adopting a deep bundle design also helps improve the air-flow distribution in the bundle. Bundles should have no more than one row per pass, and should preferably have at least two passes per row, so that the fluid flowing in two rows due to pass distribution, is mixed in later passes after exchanging heat with air at different temperatures in different rows. This phenomenon is shown in Figure 1.

To avoid such a situation, and if the tube-skin temperature cannot be achieved in conventional flow arrangement (hot fluid entering from top nozzles), a co-current arrangement is tried out where process fluid enters from bottom nozzles and moves up the bundle. Due to lower MTD in such an arrangement, the required surface area goes up further. As is usually the case, this kind of design is tube-side resistance controlling, and a bare-tube design instead of finned tube will be less expensive. Even after all these alternatives are considered, if the

TABLE 2. PERFORMANCE COMPARISON WITH TEMPERED WATER SHELL-AND-TUBE COOLER

Process fluid is same as as stated in the case study	Hydrocarbon cooling by tempered water in a shell-and-tube cooler and cooling of same tempered water cooling in an air cooler	
Type of exchanger	**Shell-and-tube**	**Air cooler**
Fluid Type	Backwash oil/ Tempered water	Tempered water/ Air
Temp, °C, In/out	204–70/60–80	80/60
Heat duty, MW	12.4	12.4
MTD, °C	45.3	
Hydrocarbon flowrate, kg/h	152,106	Nil
Tempered water flowrate, kg/h	525,668	525,668
No. of bundles/shells required	- / 3 in series	4 /-
Shell-and-tube area/ air cooler bare area, m^2	1,000	1,500
Reynolds number	1,330–50	
Exchanger cost, million $ (approximate)	0.26	0.51
Installation cost, million $ (approximate)	0.32	0.61
Total installed cost, million $ (approximate)	0.58	1.12

TABLE 3. PERFORMANCE WITH COMBINED AIR COOLER AND TEMPERED WATER SHELL-AND-TUBE COOLER

Process fluid is same as used in Table 2	Hydrocarbon cooling partly by an air cooler followed by tempered water in a shell-and-tube cooler		Cooling of same tempered water in an air cooler
Type of exchanger	**Air cooler**	**Shell-and-tube**	**Air cooler**
Fluid Type	Backwash oil/Air	Backwash oil/ Tempered water	Tempered water/ Air
Temp, °C, In/out	204/110	110–70/60–80	80/60
Heat duty, MW	9.01	3.4	3.4
MTD, °C	67.6	16.2	15
Hydrocarbon flowrate, kg/h	152,106	152,106	Nil
Tempered water flowrate, kg/h	Nil	143,757	143,757
Bundles/shells required	2 /-	Nil /2 in series	2 /-
Bare area, m^2	634	800	375
Reynolds number	16,985–2,870	351 at midpoint	
Exchanger cost, million $ (approximate)	0.23	0.16	0.16
Installation cost , million $ (approximate)	0.29	0.23	0.23
Total installed cost, million $ (approximate)	0.52	0.39	0.39

design target is a higher tube-skin temperature and a higher tube-side velocity, the Reynolds number in the transition zone is not achieved, so other alternatives must be considered, such as cooling with tempered water.

In the actual situation, the viscosity of the process fluid increases as the temperature of the process fluid falls while progressing in the tube bundle. Also, if there is mal-distribution in the air side of the multi-pass air coolers, invariably the process fluid cools more in some of tubes than in others. This will further increase the viscosity in the cooler tubes and therefore reduce flow through the tubes, which causes further cooling and more flow reduction. This process continues until ultimately, we may notice that fluid has stopped flowing in many of the tubes, and is only flowing in a very few tubes with higher velocity and turbulent flow regime. Pressure drop may be substantially higher and, unless the pump can deliver the needed head, flow may stop and

FIGURE 2. For applications where the fluid is both viscous and clean, twisted tape turbulators can be inserted into the tubes to increase heat transfer

fluid starts congealing.

The following five design steps were considered for using an air cooler (Steps 1–3), using a tempered water shell-and-tube cooler (Step 4) and a combination of the two (Step 5). The results of the performance characteristics are summarized in Tables 1–3. Several key observations are pointed out in the following paragraphs:

Step 1. The first attempt in thermal design, using a conventional counter-current flow arrangement in an air cooler, results in a Reynolds number at the outlet of 300 (deep laminar flow) and a tube-skin temperature of 50.6°C. The design also has a high tube-side pressure drop and a low tube-side velocity, in spite of 12 tube passes in an eight-tube row bundle, and therefore high surface area requirement (high cost).

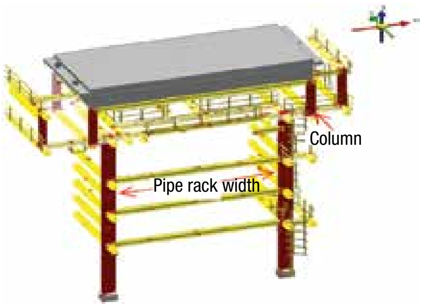

FIGURE 3. Shown here is a computer model of an air cooler mounted on the pipe rack

Step 2. By arranging the process fluid flow co-currently to air flow, the MTD goes down from 67°C (counter-current) to 57°C and therefore, the surface area requirement goes up. The existing design of four bays becomes inadequate in surface area, so one more bay is added (5 total). As the number of bays is increased, the tube-side velocity goes down further (0.47 m/s) and so does the overall heat-transfer coefficient, as tube side resistance is controlling by 85%. Even if the tube-skin temperature is improved, there is not

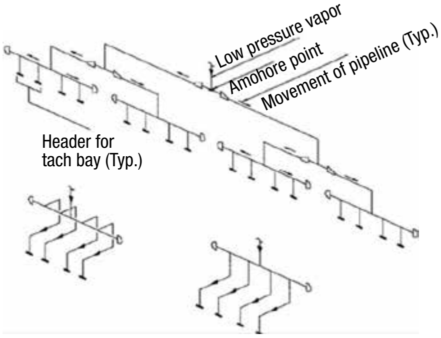

FIGURE 4. Normally, the inlet piping of an air cooler requires a symmetrical distribution

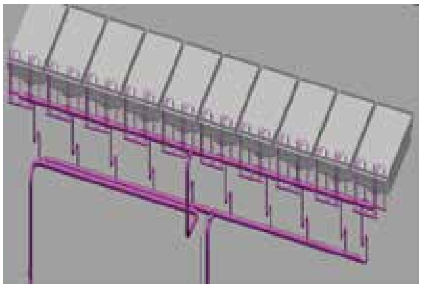

FIGURE 5. When a perfectly symmetrical distribution is not possible (as in Figure 4), an equivalent distribution of headers can be designed

much improvement in the Reynolds number, and because it is outside the user's requirement, this method is also not adequate.

Step 3. From the above, since tube-side film coefficients are very low and become controlling, there is generally no advantage in using fins on the air side to increase the overall heat-transfer rate. Bare tube bundles with a large number of rows and split passes are more practical, as shown above. The bare surface area calculated by the software is not very high, and the power requirement is also similar to the first two designs. The real advantage of using bare tube bundles is that the number of bundles is reduced from 10 to 8, while maintaining a skin temperature of 61.5°C.

Step 4. Most of the challenges seen in the designs of Steps 1–3 can be avoided if we bring tempered water as a coolant, since normal cooling water is not suitable for cooling a process fluid with high viscosity, low pour point and a limited tube-skin temperature. When the total heat duty is cooled in a shell-and-tube, tempered water cooler, the capital cost is very attractive, as shown in Table 2. However, because an air cooler is required for cooling tempered water, the costs balance out. If a tempered water system is used elsewhere in the plant that can be tweaked and ramped up to accommodate this cooler, the scheme can definitely be made attractive. However, in spite of more turbulence due to baffling in the shell side, the Reynolds number is poor, because the bulk temperature of the process fluid is 61°C in the coldest shell.

Step 5. We can split the total cooling load into two stages and use an air cooler in a series with a tempered water trim cooler. The outlet temperature (110°C) from the air cooler is high enough to have a Reynolds number above 2,000. The rest of the heat duty can be cooled in a closed-loop tempered water system, as shown in Table 3.

By opting for a combined system, the surface area is optimized substantially and the total installed cost is lower. An air cooler can handle a higher inlet temperature, and a high Reynolds number can be maintained by limiting the outlet temperature of the air cooler. Then hydrocarbon is passed through the shell side of a downstream tempered water shell-and-tube cooler where higher viscosity can be tackled better by considering rotated-square (45 deg) tube arrangement. As the bulk temperature in the shell is above 65°C, despite the low Reynolds number, heat transfer coefficient and shell side velocity are acceptable.

Therefore, we see that a combination of both shell-and-tube and air cooler play a definite role in the overall cost economics, and together they achieve more benefits when combined than when used separately.

Handling lube oil in air coolers

In off-shore platforms where space is at a premium, air coolers are used for cooling lubricant oil. Lube oil is both viscous and clean, and therefore it is possible to use turbulence promoters (Figure 2) or tube inserts (turbulators) in this type of air cooler. Such inserts can increase the tube-side heat-transfer coefficient by 100–250% over bare tube exchangers, with an increase in pressure drop, but without much increase in velocity. Twisted tape turbulators are formed into a helical fashion and they increase heat-transfer efficiency by breaking up the laminar flow pattern of fluids inside the tubes. The swirling fluid promotes greater contact with the tube wall (increasing shear stress at the walls many times more) enhancing tube-side convective heat transfer efficiency. The increase in values of Nusselt number, Reynolds number, Prandtl number, pressure drop and friction factor will depend upon the configuration of twisted tape (twisted ratio, pitch ratio, tape width, wire diameter and so on).

Structural considerations

Support options. For an air-cooled exchanger, there are two support options: 1) to place it on pipe rack or 2) to place it on a separate structure supported from the ground. Even though air-cooled exchangers require more space than water-cooled exchangers, the majority of space problems can be resolved if they are placed on a pipe rack (Figure 3). Normally the tube bundle length is fixed, based on the width of the pipe rack. If the pipe rack width is 9 m, the tube length could be 9.5 to 9.7 m. The supporting legs of the air-cooler bundle are fixed on the main civil or structural beams, which simplifies the pipe rack design. At the same time, it is desirable to adjust the pipe rack or the structure longitudinal column spacing, based on the width of the air-cooler bundle, so that the bundle legs sit straight on top of the columns. Sometimes, it may not be possible to adjust spacing, since each tube bundle might have different widths, depending on service condition. Therefore, adjusting the pipe rack columns for different widths may not be feasible from a structural design and detailing point of view.

Walkways. There will be walkways between sets of air coolers across the length and near the headers for facilitating operators to inspect the bundle or operate the valves. The width of these walkways is generally 1.5–2.0 m. Air coolers must have access platforms mounted all around on the structure to provide maintenance. Air coolers have motors hanging at the bottom of the air-cooler plenum. Hence, it is required to have access platforms underneath the cooler for maintenance of the motors. A regular staircase should be provided for accessing

the air cooler platforms or motor maintenance platforms. Monkey ladders are also provided in addition to a staircase from the structure.

Piping considerations. For a minimum of two fans per bay, the height of the underside of the fan inlet bell (for forced-draft units) or of the underside of the bundle (for induced-draft units) should be at least 2 m or one fan diameter (whichever is the greater) above the ground level, elevated floor or pipe bridge. The air coolers on the pipe rack should be located in such a way that the bundles are accessible with a crane — at least from one side.

Normally, the inlet piping of an air cooler requires a symmetrical distribution for condensers. Therefore, the number of bays/bundles is based on 2^n = 2, 4, 8, 16, 32 ... (Figure 4). When such an exact symmetry is not possible due to some constraint, such as pressure drop or structural limitation, efforts should be made to maximize an equivalent symmetry, as shown in Figure 5, where a total of ten bays are divided into five bays both sides and vapor is distributed equally to both sides. The piping of the air cooler needs to be supported, so either the structural columns or the pipe-rack structural columns need to be extended upwards to properly support the piping. Such data have to be given at a very early stage in the project, since this needs to be considered during the design of the pipe rack.

The air coolers for an overhead system are normally used when a large quantity of vapor is required for condensation or a huge quantity of gas or liquid needs to be cooled. The major points that need to be taken care of when routing the inlet and outlet pipes are as follows:

1. If the supply line has a very low operating pressure, which is usually the case for connecting a distillation column, care needs to be taken to keep the number of bends or elbows leading to the air cooler at a minimum. But functionality and stress requirements have to be considered. The length of all branch pipes for all tube bundles from its header has to be more or less similar to keep the pressure drop the same; this will ensure equal distribution of fluids to all bundles.
2. Normally, the inlet-side header box is considered as fixed for the piping connection and the other header is floating. But the bundle can move in transverse direction of tubes by a few millimeters (say, 6 mm minimum) or if it is fixed at one edge, then it can move by a higher margin (say, 12.7 mm minimum) in the other direction, as per American Petroleum Institute (API, 7th edition) recommendations. Usually, this value can be anywhere between 5 and 60 mm. This header displacement is necessary to compensate for piping inlet/outlet header expansion. The value decided upon should be confirmed with the vendor of the air cooler, since the vendor may use a different displacement provision.

TABLE 4. OVERHEAD CONDENSER PERFORMANCE WITH RESPECT TO AIR AMBIENT TEMPERATURE			
Air cooler used alone (at lower ambient temperature)			
Air ambient temp, °C	50°C	42°C	34°C
Process fluid temp, °C	65	53.7	42.6
Heat duty, MW	55.8	58.7	61
Shaft power requirement, kW	390	370	350
Air cooler and trim cooler combination (per design) with air flow optimized for lower ambient temperature			
Heat duty, MW	55.8	55.8	55.8
Air flowrate, kg/h	5,902,853	4,421,612 (75%)	3,467,826 (59%)
Shaft power requirement, kW	390	180	104
Saving in shaft power per year (8,000 h), MW		1,680	2,288

The movement of tube bundles in the transverse direction could occur only when the piping connected to equipment nozzles generates enough force to overcome the friction at the bundle supports. That is why it is a common practice to provide stainless steel, polytetrafluoroethylene (PTFE) or other type of plate at the support point to ease the movement. But this must be done in consultation with the vendor.

3. The loads created on the bundle nozzle — due to thermal expansion, the weights of the pipe, insulation and fluid, and the inside pressure of piping — should be less than the limits given by API. Sometimes the vendor allows a higher allowable load (normally two times the code value).

Locating shell-and-tube coolers. The standalone water condenser and shell-and-tube trim water cooler can be placed above the condenser drum on a structural platform supported from grade. Even though a shell-and-tube water cooler will require less space than an air cooler, some area allocation is needed on the ground (or on the platform for off-shore applications). The pressure of the cooling water reaching to the tube side of condensers and trim coolers (when on a platform) is very important for proper functioning of the condenser and the trim cooler. If the pressure drop in the cooling water circuit is not properly calculated while designing the inlet/outlet piping, the actual cooling water flowrate will be lower than that of the design calculation, and the performance may suffer as a result.

Flexibility. The operating costs for the air cooler include the electrical power required to operate the fans and sometimes power is required for heating coils in cold climates. Normally, the design of the cooler will be such to accommodate the highest expected ambient temperature (for example, 50°C), but because of seasonal changes, such a strategy would be wasteful during the periods when the ambient temperature is lower (for example, 40°C) — which can be as much as 50% for the year. Operating power costs can therefore be much lower than the installed power costs by using two-speed motors, auto-variable pitch fans and variable frequency drive (VFD) fan-motor control to reduce the air flow. In temperate climates, as much as 50% or more of the design power may be saved over the course of a year with auto variable-pitch fans.

Nowadays, VFD technology has become popular and more common rather than auto variable-pitch fans, which are problematic for a number of reasons. The air requirement can be adjusted from 10 to 100% through VFD control. Table 4 presents the potential savings that can be expected by adjusting the power requirements to different ambient-air temperatures, for both a standalone air cooler, and for a combination of air cooler and trim cooler. When the ambient temperature drops to below 34°C — which can occur during 5 to 6 months over the year, the trim cooler may not even be required at all, since the total heat duty can be handled by air cooler alone. So in addition to the power savings, there will be additional savings for not using cooling water, which can cost around $0.4 million/yr. If a refinery decides to keep both air coolers and trim coolers on line, power saving through reduction of air flow via VFD is very substantial, as shown in Table 4.

Such flexibility is not possible using only shell-and-tube coolers, where operators only very rarely will adjust the cooling water flowrate by operating exchanger valves (manually or automatically). Therefore, we see that shell-and-tube and air coolers both have definite roles in the overall cost economics.

Weatherizing for colder climates. In some parts of the world, where ambient conditions are such that in winter, air temperature dips below freezing, temperature control of the process streams at the air-cooler outlet is required to prevent freezing of low pour-point hydrocarbons. This leads to a more complicated design for the air cooler.

When a minimum tube-wall temperature has to be maintained in the air cooler, a recirculation system is employed whereby automatic louvers at the top and sides of the air cooler housing (containing the entire assembly of tube bundles, ducting, steam coils, plenums and fan motors) control the extent of recirculation. The recirculation is possible in forced-draft air coolers, since hot exhaust air can be recirculated through a duct-and-louver system.

A steam coil is generally a separate tube bundle of one or two rows having a length and width similar to the main air cooler, that is placed below the main air cooler bundle. If an electric fan heater is to be provided in place of a steam-heated bundle, the same is placed below each air cooler fan. Low-pressure (LP) steam being inside finned tubes, the steam-heated bundle and louver will involve additional pressure drop in the fan design. Closing the louver on top of a bundle allows the heating coil to warm the bundle during start up in freezing weather, so that the material in the bundle will not freeze or solidify. A steam coil is also used to temper very cold air to the bundles in continuous operation while the fan is operating and the exhaust louver is open. When two fans are operated per bay, an auto-variable-pitch fan or fan with VFD is kept at rear end of the bundle, so that the process fluid outlet temperature can be controlled.

Controlling recirculation. A part of the air leaving from the top of the

system is recirculated and mixes with fresh air entering from the sides so that the combined temperature is precisely the design ambient temperature. The lower the ambient temperature, the greater will be the extent of recirculation.

For startup, when ambient temperature is lower than design ambient temperature, ambient air can be passed through a live-steam coil, located below the bundle, such that air approaching the bundle is heated up to the design temperature. The recirculation of exit air is gradually increased, which reduces the steam requirement. Eventually, the steam supply can be stopped altogether.

The air cooler is fitted with a duct leading from the top outlet to the bottom inlet. Louvers are placed in the bypass duct, at the air inlet and at the air outlet. The temperature of air just below the tube bundles will regulate the opening and closing of inlet and bypass louvers, whereas the process outlet temperature will regulate the opening and closing of the outlet louver. The duct sizing calculation and differential pressure drop across the dampers is carefully done to avoid failure of the system. The vendor's scope of work will include the design of the louvers. In general, air-cooler tube-skin temperature is kept 15–20°C above the tube-side fluid pour-point temperature through this elaborate system.

Although the cost of such an air cooler is quite high, it is still preferred in colder climates to prevent icing or frosting. ■

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3RD ANNUAL CONNECTEDPLANT CONFERENCE
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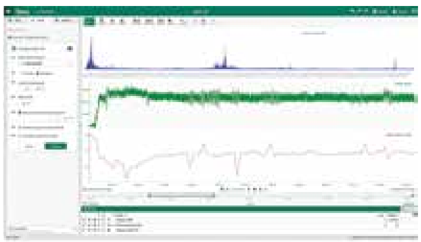
The 2019 Connected Plant Conference (www.connectedplantconference.com) is being held February 19–21 in Charlotte N.C. The event will bring together experts from around the globe to discuss the practical implementation of Industrial Internet of Things (IIoT) and other digital technologies in the chemical process industries (CPI) and the energy sector. The conference will kick off with the "Introduction to All Things IIoT Workshop" and will continue over the next two days with a comprehensive program covering risk management, asset optimization, security, maintenance, meeting customer needs and much more. The event will conclude with a panel of end users discussing their experiences with digitalization, including input from DuPont (Wilmington, Del.; www.dupont.com), Covestro AG (Leverkusen, Germany; www.covestro.com), Black & Veatch (Overland Park, Kan.; www.bv.com), Siemens AG (Munich, Germany; www.siemens.com) and more. The Connected Plant Conference also includes exhibitors who will showcase their newest IIoT technology offerings. The following is a small selection of the digital technologies offered by the 2019 Connected Plant exhibitors.


Seeq

This analytics platform features customizable data scorecards

R21 (photo) is the latest release of this company's analytics platform for process manufacturing, including chemicals, petroleum refining, pharmaceuticals, mining and more. New R21 features reflect both the growing need to share analytics-based insights across organizations, and the increased complexity of the use cases where engineers need to analyze process data. For publishing insights, R21 offers expanded "scorecards," a feature for the display of calculated tables used for tabulated metrics, measurements and other summary data. Scorecards may be presented in tables with conditional formatting support and user-defined columns. R21 also adds frequency-analysis capabilities, often referred to as "FFT," to transform segments of a time-series signal into the frequency domain. Users access the frequency analysis tool via an intuitive panel that guides them through the transformation process and displays results as a power spectrum, or they can access FFT functionality as a formula in the R21 scripting environment. Booth 306 — *Seeq Corp., Seattle, Wash.*
www.seeq.com


Gardline Communications

Global satellite communications targeted for industrial users

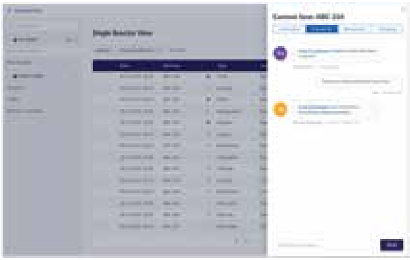
This company provides satellite communication equipment for voice, data, email and IIoT, specializing in satellite phones, fixed and mobile communication systems, satellite-integrated supervisory control and data acquisition (SCADA), system monitoring and asset tracking (photo). The 9555 Satellite Phone provides voice and texting capabilities, and is lightweight, rugged and easy to carry. The company's BGAN Portable Office system enables internet service in remote locations with voice and high-speed data capabilities for one or several people. Booth 304 — *Gardline Communications (GComm), Houston*
www.g-comm.us


Schneider Electric

This control software simplifies commissioning

EcoStruxure Foxboro DCS Control Software 7.1 (photo) is designed to improve the realtime efficiency, cybersecurity, reliability and profitability of assets and operations. New features of this software release bring the EcoStruxure Field Device Expert suite of functions, which includes: the Intelligent Commissioning Wizard, which can reportedly reduce commissioning time by up to 75%; the Device Replacement Wizard, which greatly simplifies replacement and commissioning of HART devices; and the Bundled HART DD library, which eliminates version mismatch and cybersecurity risks. Version 7.1 also increases reliability with realtime asset-health condition monitoring and the Control Editors Activity Monitor, which is designed to enhance communication and collaboration across the workplace. EcoStruxure Foxboro DCS Control

TrendMiner



Fero Labs

Siemens

Software 7.1 runs on Windows 10 and Windows Server 2016, to ensure flexibility and robust cybersecurity. Booth 310 — *Schneider Electric, Foxboro, Mass.*
www.schneider-electric.us

Digital insights into critical heat-exchanger operation

OMNI is a digital platform designed to improve critical heat-exchanger performance. OMNI can predict fouling and operational issues, prevent unscheduled outages and prolong runtimes and asset life, says the manufacturer. The platform combines water- and process-side data, which are run through a secure, Microsoft-powered calculation engine. The data are analyzed in realtime, while a team of engineers monitor the data continuously for irregularities. The information is displayed on a powerful dashboard that provides realtime access to the assets across an organization. An onsite simulation system matches the exact conditions of users' heat exchangers to provide a realistic view of conditions. Lastly, this company's audit team reviews the entire plant annually to monitor the overall health of the complete water system. Booth 202 — *Nalco Water, an Ecolab Company, Naperville, Ill.*
www.ecolab.com/nalco-water

New recommendation engine enables root-cause analyses

ContextHub is a new suite of capabilities available with Version 2018. R2, the latest release of this company's self-service analytics software (photo). ContextHub is said to significantly increases the flexibility of annotation, providing experts new insights into their data. ContextHub is a repository, search engine and collaboration platform for context items that can be neatly aligned to assets, processes and events. The platform can be configured for the context itself to become a new dataset that can be both visualized and analyzed. It also serves as a starting point for time-series analytics. Other new features in Version 2018.R2 include a related context item search for fast filtering of time-series data and further extensions to the Recommendation Engine machine-learning tool, which helps to speed up root-cause analysis of process anomalies. Booth 103 — *TrendMiner N.V., Hasselt, Belgium*
www.trendminer.com

Machine learning speeds up analytics projects

This company provides actionable machine-learning software technologies for chemical processors to improve plant yield, increase product quality and better understand root causes of production issues. According to the company, advanced analytics projects that can typically span several weeks or months can be conducted within hours using this software tool. The software is designed so that no prior data-science expertise is required for use. The data-cleaning and machine-learning model-generation steps are automated so that users can spend more time taking action to improve processes. Booth 101 — *Fero Labs, New York, N.Y.*
www.ferolabs.com

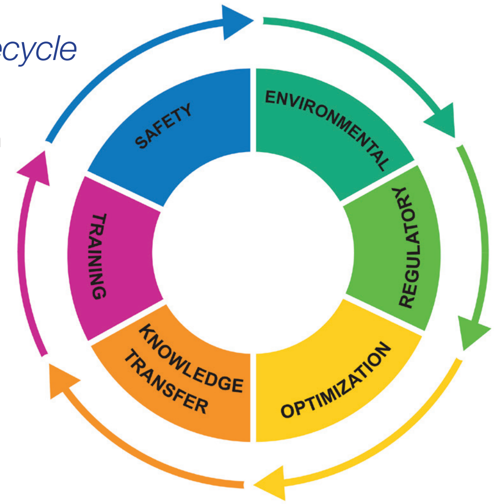
This VR platform is now accessible on mobile devices

The Comos Walkinside virtual-reality (VR) platform (photo) for operating, training and simulation has recently been integrated with the PureWeb Platform. The PureWeb Platform provides comprehensive tools for remotely accessing, delivering and interacting with 2-D and 3-D models in real time. This enables Comos Walkinside viewers to realistically depict highly complex plant models in several dimensions using any web browser or mobile device. Integration of the platforms enables powerful rendering on a server and secure delivery of the images to a web browser or mobile device as part of an interactive stream, achieving a high level of image fidelity. This allows simultaneous collaboration from disparate geographic locations in real time, also creating new workflows for Comos Walkinside that were not possible before, says the company. Booth 203 — *Siemens AG, Munich, Germany*
www.siemens.com ■

Mary Page Bailey

Emerson's digital twin delivers a key technology for digital transformation

Dynamic simulation drives improvement across the plant lifecycle



Efficiently maintaining a process, asset, or plant across its entire lifecycle is the foundation for driving return on investment and stakeholder value. As digital transformation continues to revolutionize industrial manufacturing, organizations are using the digital twin to connect the physical and virtual worlds, making lifecycle management a core strategy. Digital twin simulation helps leverage data across the lifecycle to optimize process efficiency and drive better decisions from the earliest stages of capital projects through operations.

Improved Capital Projects

Emerson's digital twin is a lifecycle dynamic simulation, enabling organizations to easily leverage steady-state design models from Aspen HYSYS® for developing dynamic process models early in project execution. Project teams can evaluate process and control design philosophies early and detect and resolve issues before any changes will impact the project schedule, helping to keep projects on time and on budget.

As the project phase moves from design to construction, the digital twin can be used to train operators and assess workforce competencies prior to startup—well before equipment even begins arriving on site. Concurrently, the project team uses the digital twin to perform virtual commissioning and factory acceptance testing, taking those key items off the critical path.

From Project Certainty to Operational Certainty

After project completion, Emerson's digital twin simulation continues to provide value by delivering operational excellence benefits across the lifecycle of the plant. Using simulation, engineers can develop, test, and demonstrate process control improvements without impacting the operation or production of the actual plant.

Emerson's lifecycle digital twin offers features beyond the capabilities of traditional simulation, making them useful for plants and projects of all sizes. Selective fidelity, support for highly automated plants, and additional features for validated industries deliver flexibility for each project's needs. Learn about how Emerson's digital twin can help enable your digital transformation by reading our full white paper at

www.emerson.com/digitaltwin

ecom instruments—Intrinsically Safe Mobile Devices

Staying connected even in hazardous areas

ecom instruments is an international technology leader and the world's foremost manufacturer of mobile devices for hazardous areas. ecom is known for such innovative products as Smart-Ex® 01, the world's first Zone 1 / Div. 1 Android 4G/LTE Smartphone; Tab-Ex® 01, the world's first Zone 1/Div 1 Android 4G LTE tablet; the Pad-Ex® 01 Windows tablet for Zone 2 / Div. 2; and i.roc® Ci70 –Ex, the world's first PDA with modular head modules for 1D/2D Multi-Range Barcodes.

Building on the foundation of the world's first series of tablets for hazardous areas, the second-generation Tab-Ex® 02 offers innovative features that make Industry 4.0 / Internet of Things (IIoT) applications easy to implement. The Tab-Ex 02 is ideally suited for IIoT-capable applications in industrial settings, which includes simplifying data exchange with SCADA/DCS systems. With the military-grade certified[1] Samsung Galaxy Tab Active2 technology enabling access in rainy or inclement weather, workers can use the touch screen while wearing work gloves or the S Pen while in the rain. The compact, lightweight tablet is the ideal companion for a wide range of tasks such as inventory, material tracking, maintenance, and supply chain and asset management. The Tab-Ex 02 is currently available in an ATEX/IECEx Zone 2 / Div. 2 certified industrial version. The Tab-Ex 02 DZ1, certified for ATEX/IECEx Zone 1 / Div. 1, will be available early 2019.

ecom products enable today's Mobile Workers to operate even more efficiently and safely with multipurpose hardware, applications, service and support. Mobile users can safely communicate in real-time—anytime, anywhere—as well as collect and retrieve data, parameters and information remotely. Video conferencing is one example of how mobile wireless solutions in hazardous areas open up new communication methods for documentation, remote diagnostics and maintenance. At the point of inspection or while maintenance work is executed, the Mobile Worker simply streams videos directly from the hazardous area to experts at the control center. This allows a remote diagnosis in real time and enables appropriate measures or repairs to be initiated immediately without incurring costly downtime.

As part of the **Pepperl+Fuchs** Group, a global leader in explosion protection and sensor technology, ecom can offer customers access to a comprehensive product portfolio for hazardous areas. For more information, visit

www.ecom-ex.com and www.pepperl-fuchs.com.

[1] MIL-STD-810G and IP68-certification

Economic Indicators

2016 2017 2018

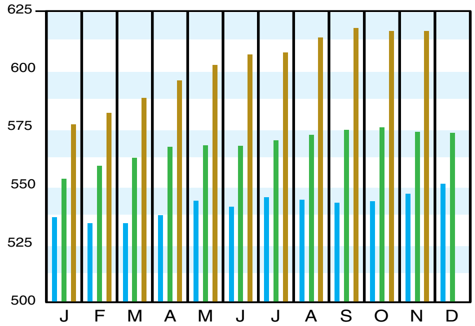
Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Nov. '18 Prelim.	Oct. '18 Final	Nov. '17 Final
CE Index	616.4	616.3	573.2
Equipment	752.4	751.5	692.5
Heat exchangers & tanks	671.4	666.9	604.4
Process machinery	732.6	728.3	693.2
Pipe, valves & fittings	973.6	982.8	900.1
Process instruments	420.9	419.7	411.6
Pumps & compressors	1036.3	1038.0	995.9
Electrical equipment	552.8	552.6	523.5
Structural supports & misc.	832.5	830.6	731.7
Construction labor	337.8	340.4	329.5
Buildings	600.6	601.2	567.5
Engineering & supervision	316.8	316.6	308.6

Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

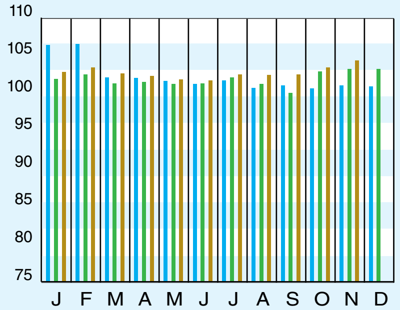
Annual Index:
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5



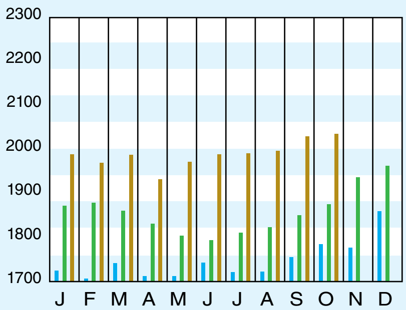
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2012 = 100)	Dec. '18	=	104.3	Nov. '18	=	103.4	Oct. '18	=	102.8	Dec. '17	=	101.7
CPI value of output, $ billions	Oct. '18	=	2,035.8	Sept. '18	=	2,029.1	Aug. '18	=	2,008.6	Oct. '17	=	1,841.4
CPI operating rate, %	Dec. '18	=	77.4	Nov. '18	=	76.8	Oct. '18	=	76.4	Dec. '17	=	76.2
Producer prices, industrial chemicals (1982 = 100)	Dec. '18	=	260.7	Nov. '18	=	279.2	Oct. '18	=	287.7	Dec. '17	=	266.0
Industrial Production in Manufacturing (2012 =100)*	Dec. '18	=	106.2	Nov. '18	=	105.1	Oct. '18	=	105.0	Dec. '17	=	102.9
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '18	=	186.3	Nov. '18	=	186.3	Oct. '18	=	183.9	Dec. '17	=	184.0
Productivity index, chemicals & allied products (1992 = 100)	Dec. '18	=	97.6	Nov. '18	=	96.9	Oct. '18	=	96.9	Dec. '17	=	99.4

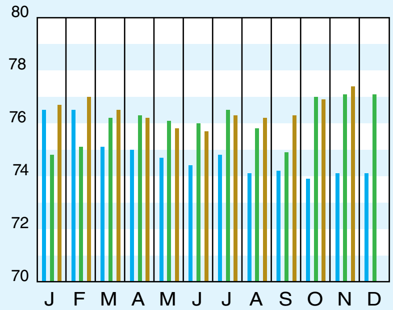
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the November 2018 *CE* Plant Cost Index (CEPCI; top; most recent available) remained the same as the previous month's value, although the final value for October was downwardly revised by a tenth of a point. The Equipment, and Engineering & Supervision subindexes increased slightly for November, but the rises were offset by decreases in the Buildings and Construction Labor indexes. The result was an unchanged overall CEPCI value for November, that now stands at 7.5% higher than the corresponding value from November 2017. Meanwhile, the CBI numbers (middle) are not fully updated because some data are unavailable due to the ongoing U.S. federal government shutdown.